A STUDY OF FORAMINIFERA FROM LER HILL, KACHCHH, GUJARAT

ABSTRACT

OF THE

THESIS

SUBMITTED FOR THE AWARD OF THE DEGREE OF

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IN

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BY

S. M. SHARIQUE FAISAL

DEPARTMENT OF GEOLOGY
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ABSTRACT

The Jurassic rocks of Kachchh are widely distributed, well-exposed and richly fossiliferous. A large volume of literatures published on different geological aspects of these sediments, especially palaeontology and stratigraphy, have made these rocks famous all over the world for their excellent exposures as well as well preserved and varied megafossils, particularly ammonoids. The micropalaeontological investigations of these rocks are scanty. However, in the past two decades some significant foraminiferal investigations of the Jurassic sediments of Kachchh have been carried out but these studies deal mainly with taxonomy and biostratigraphy and few detailed palaeoecological and biogeographical studies employing microfossils have been attempted so far. Therefore, more intensive and extensive foraminiferal studies, with special emphasis on palaeoecology and palaeobiogeography, of Jurassic foraminifera of Kachchh are required. The present study dealing with the Jurassic foraminifera of Ler hill is a contribution in this direction.

The Kachchh region is bounded by Little Rann in the east, Arabian Sea in the west, Gulf of Kachchh in the south and Great Rann in the north. A well exposed thick sequence of about 2000 to 3000 meters, ranging in age from Jurassic to Recent, includes both marine and non-marine sediments. These rocks crop out principally in three parallel east-west trending anticlinal ridges and an isolated rock mass in the east. The Kachchh Jurassic overlies a Precambrian crystalline basement (? Erinpura Granite) exposed at Meruda hill in the great Rann of Kachchh. Jurassic rocks of Kachchh outcrop mainly in the form of structural domes and have been intruded by numerous sills and dykes which are part of the Deccan Trap igneous activity. A number of classifications were proposed for Mesozoic succession of Kachchh. However, For the purpose of the present study, the classification proposed by Sastry and Mamgain (1971) which is adapted and modified by Kumar (1985), with certain modifications in ages as a result of recent researches, has been followed. According to this classification the Mesozoic

succession of Kachchh is divided into five formations, *viz.*, Patcham, Chari, Katrol, Umia and Bhuj in ascending order, ranging in age from Bajocian to post-Aptian.

The study area, *viz.*, Ler hill, is located in the neighborhood of Ler village nearly 12 km SSE of Bhuj, lying between the longitudes 69° 41' 30" and 69° 45" east and latitudes 23° 10' 30" and 23° 12' 30" north. A well exposed section of Chari and Katrol formations exposed on the northern flank of the Ler hill was selected for foraminiferal investigations. The entire Chari sequence was divided into seven litho-units. The main rock types in the study area are shale, limestone, sandstone, and conglomerate. A total of thirty-three bed by bed samples were collected mainly on the basis of lithological variation and subjected to processing for retrieving foraminiferal tests.

A prolific foraminiferal assemblage comprising a total of forty-two species has been recovered from the Jurassic sediments exposed at Ler hill, Kachchh. Of these, fifteen are being described for the first time from the Indian region, *viz.*, *Saccammina* cf. *S. franconica*, *Reophax metensis*, *Reophax* aff. *R. scorpiurus*, *Kutsevella spilota*, *Bulbobaculites vermiculus*, *Laevidentalina* aff. *D. oppeli*, *Pseudonodosaria vulgata*, *Lenticulina ectypa*, *Lenticulina protracta*, *Neoflabellina ovalis*, *Marginulina caelata*, *Marginulina* aff. *M. sculptilis*, *Vaginulinopsis misrensis*, *Epistomina parastelligera* and *E. tenuicostata*.

The Ler foraminiferal assemblage includes four suborders, *viz.*, Lagenina, having twenty-six species (61.90%), Textulariina represented by fourteen species (33.33%), and Involutilina and Spirillina having one species each representing 2.38% of the total species. Family Vaginulinidae dominates the assemblage which comprises sixteen species belonging to seven genera, covering 38.09% of the total species. Other families are Lituolidae having five species belonging to two genera (11.90%), Nodosariidae including five species belonging to four genera (11.90%), Epistominidae having five species belonging to one genus (11.90%), and

Hormosinidae comprising four species of one genus (9.52%). Families Saccamminidae, Ammobaculinidae, Haplophragmiidae, Spiroplectamminidae. Textulariidae, Involutinidae, and Spirillinidae each having one species belonging to one genus and constitute 2.38% each of the total foraminiferal species. Detailed systematic study supported by SEM photographs of all the species have been carried out.

Foraminifera have been used to date these sediments. Although most of the species are rather long ranging, on the basis of some fairly short-ranging foraminiferal species restricted within Callovian–Oxfordian or occurring frequently during this time span at different places of the world, a Callovian to Oxfordian age is assigned to the sequence exposed at Ler hill, Kachchh.

An attempt is made to demarcate the Callovian/Oxfordian boundary in the Ler hill sequence. The lower portion from Litho-unit I to Litho-unit V contains some foraminiferal species representing Callovian, *viz.*, *Epistomina regularis*, *Reophax metensis*, *Ammobaculites fontinensis*, and *Astacolus anceps* while upper portion from Litho-unit VI to Litho-unit VII comprises Oxfordian species, *viz.*, *Marginulina oxfordiana*, *Marginulina sculptilis,* and *Epistomina tenuicostata*. Thus the Callovian/Oxfordian boundary in the present Chari sequence lies in between litho-units V and VI (sample number L 26 and L 27).

The foraminiferal assemblages has been employed to interpret the palaeoecology and depositional environment of the Jurassic sequence exposed at Ler. Using a number of currently used techniques, *viz.*, α-index, test composition, morphogroups, and data on individual genera and families the Ler hill foraminiferal assemblage is divided into five sub-assemblages representing different bathymetric and environmental conditions. On the basis of the palaeoecological analysis, it is reasonable to visualize that the overall deposition of the Chari sequence exposed at Ler hill, Kachchh, took place in a near-shore, shallow marine environment in the middle to outer shelf region with the depositional basin being tectonically rather unstable with frequently fluctuating shoreline.

The Jurassic foraminiferal assemblage recovered from the Ler hill sequence includes a number of species which are widely distributed throughout the world. The present Jurassic foraminiferal assemblage compares well with those of Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia, and Madagascar and belongs to Indo-East African Province of the Tethyan Realm. This Province occupied the shallow waters of the Indo-Malagasy or Indo-East African Gulf. It is further visualized that Kachchh region was having close sea connection with Rajasthan. Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia, and Malagasy during Middle to Upper Jurassic time.

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2008

Dr. Abu Talib
M.Phil., Ph.D.
READER

DEPARTMENT OF GEOLOGY
ALIGARH MUSLIM UNIVERSITY
ALIGARH-202002

Tel : Office: +91-571-2700615
Fax : +91-571-2700528
Mob : +91-9897215631
e-mail : talib04@rediffmail.com

22nd September, 2008

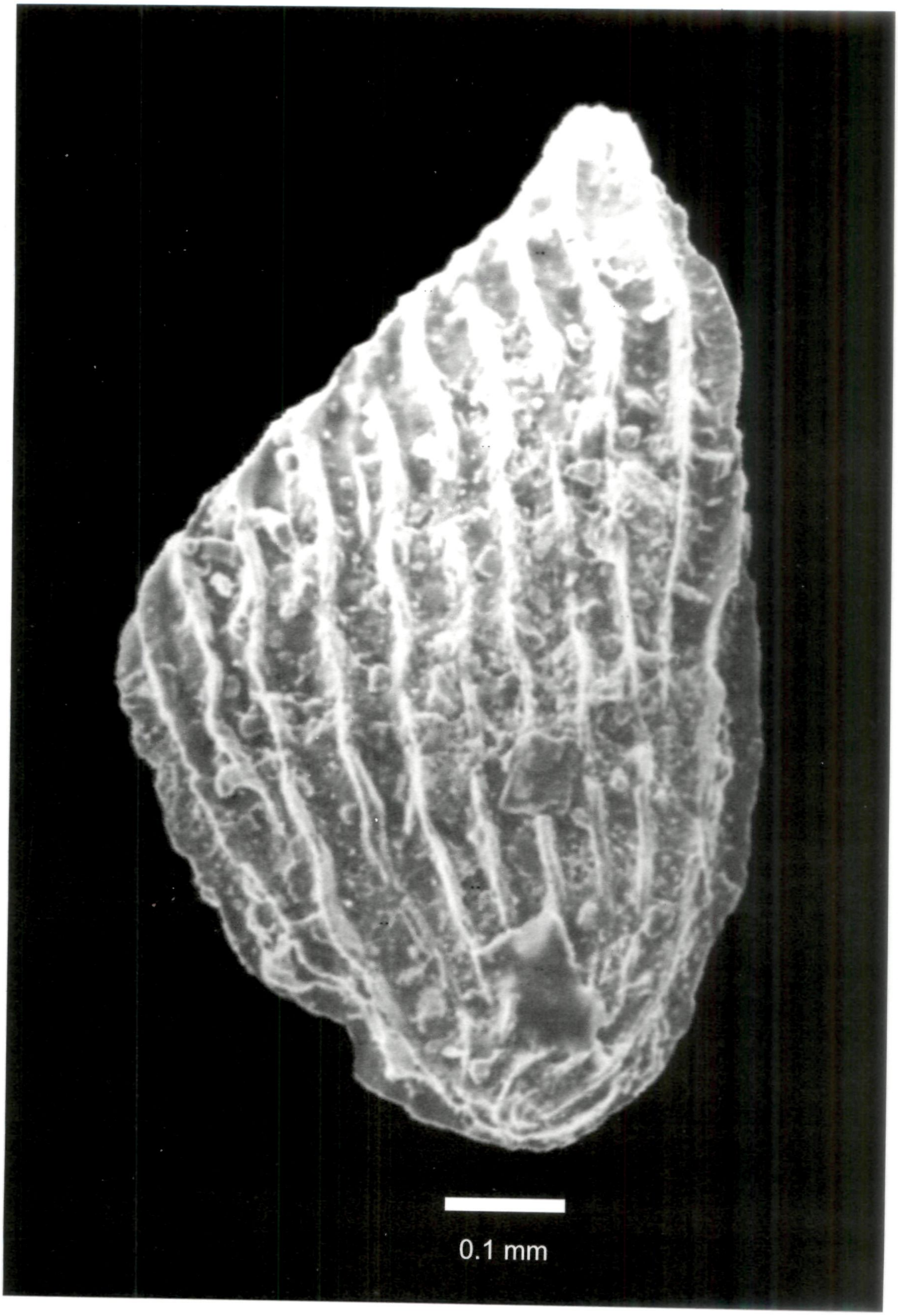
CERTIFICATE

This is to certify that Mr. S. M. Sharique Faisal has completed his research under my supervision for the degree of Doctor of Philosophy of the Aligarh Muslim University. This work is an original contribution to our knowledge of the Foraminifera from the Jurassic of Kachchh and has not been published anywhere either in part or in full.

He is allowed to submit the work for the Ph. D. degree of the Aligarh Muslim University, Aligarh.

A. Talib

Abu Talib
Supervisor



Citharina clathrata (Terquem)
Chari Formation, Ler hill, Kachchh

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(S. M. Sharique Faisal)

Department of Geology
Aligarh Muslim University
Aligarh-202002

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE OF THE STUDY

In the Indian subcontinent the Jurassic marine strata are mainly exposed in the Kachchh (variously spelt as Cutch, Kutch, and Kachchh) region, with an estimated thickness of about 1625 meters and ranging in age from Bajocian to Tithonian. Since the beginning, this region has been known as a seismically active zone on the Indian Plate and the catastrophic earthquake of 1819 provided impetus for geological research in the region. Beginning with 1834, a large volume of literature accumulated on different geological aspects of these sediments, especially palaeontology and stratigraphy, making these rocks famous all over the world for their excellent exposures as well as well preserved and varied megafossils, particularly ammonoids.

The January 26, 2002, Bhuj earthquake, once again, attracted the attention of global geological community to this region. Although considerable work has been carried out on megafossils and stratigraphy of these sediments, microfossils entombed in these rocks have not been paid due attention.

The Jurassic rocks of Kachchh attracted the attention of micropalaeontologists following the encouraging results obtained in petroleum prospecting by the Oil and Natural Gas Commission of India. However, only few workers, i.e., Bhalla and Abbas (1978), Bhalla and Talib (1991), and Pandey and Dave (1993) have made some significant foraminiferal investigations of the Jurassic sediments of Kachchh. These studies deal mainly with taxonomy and biostratigraphy and no detailed palaeoecological and biogeographical studies employing microfossils have been attempted so far. Therefore, more intensive and extensive studies on Jurassic microfossils of Kachchh, especially foraminifera which are abundant and well preserved in these sediments, are required in order to draw a vivid picture of

Figure 1

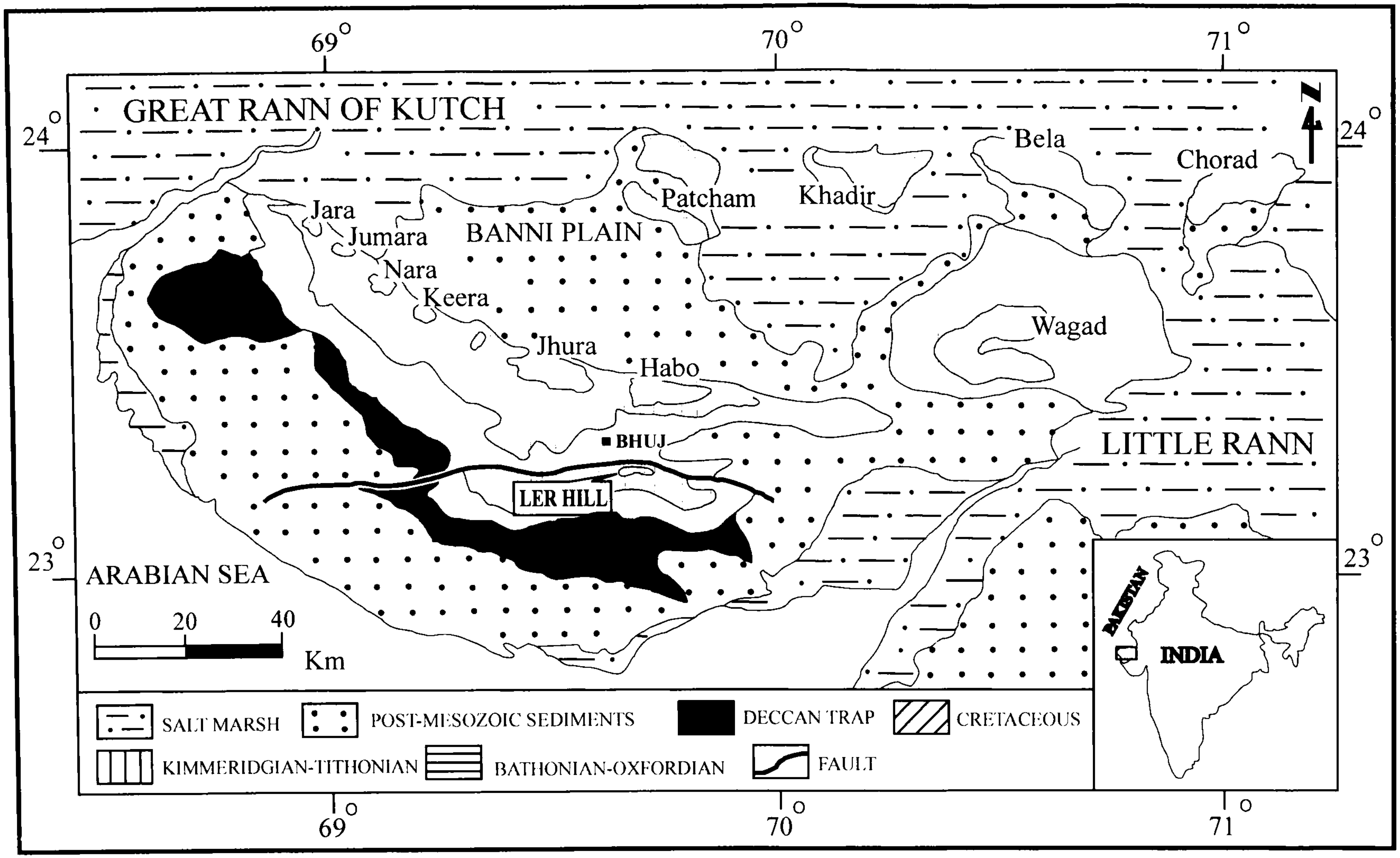


Figure 1. Geological map of Kachchh showing Ler hill (after Fürsich *et al.*, 1991)

the foraminiferal assemblage, microbiostratigraphy, palaeoecology, and palaeobiogeography of the Jurassic sediments of this region.

The Jurassic rocks of Kutch are exposed as domal outcrops in three east-west trending ridges. The middle ridge is the most prominent where a number of large domal exposures are located. Most of the micropalaeontological studies are confined to these large outcrops in the middle ridge north of Bhuj, the district headquarters of Kachchh, and practically no attention is paid to the micropalaeontological investigations of the smaller domal outcrops situated south of Bhuj (figure 1).

Keeping the above in mind, the present study is undertaken which deals with the foraminiferal investigation of a relatively small but well developed domal exposure of the Jurassic rocks, i.e., Ler hill, lying about 12 km SSE of Bhuj.

1.2 SCOPE OF WORK

A rich foraminiferal assemblage has been recovered from the Ler hill, Kachchh, comprising forty-two species. A number of species are being described for the first time from the Indian subcontinent. The assemblage is dominated by Vaginulinidae and Nodosariidae representing 38.09% and 11.90% respectively of the total population. These two families together are well known to exhibit a wide range of inter- as well as intra- specific variation and a detailed taxonomic study of the foraminiferal assemblage constitutes a substantial portion of the present study.

On the basis of the foraminiferal assemblage an attempt has been made to interpret the depositional environment of the studied Jurassic sequence exposed at Ler hill. Based on foraminiferal assemblage, using several advance techniques for paleoecological interpretation such as morphogroup analysis, fisher index, and test composition, a fairly accurate picture of the depositional environment with particular emphasis on palaeobathymetry, palaeooxygenetion and palaeosalinity of these sediments could be visualized.

Figure 2

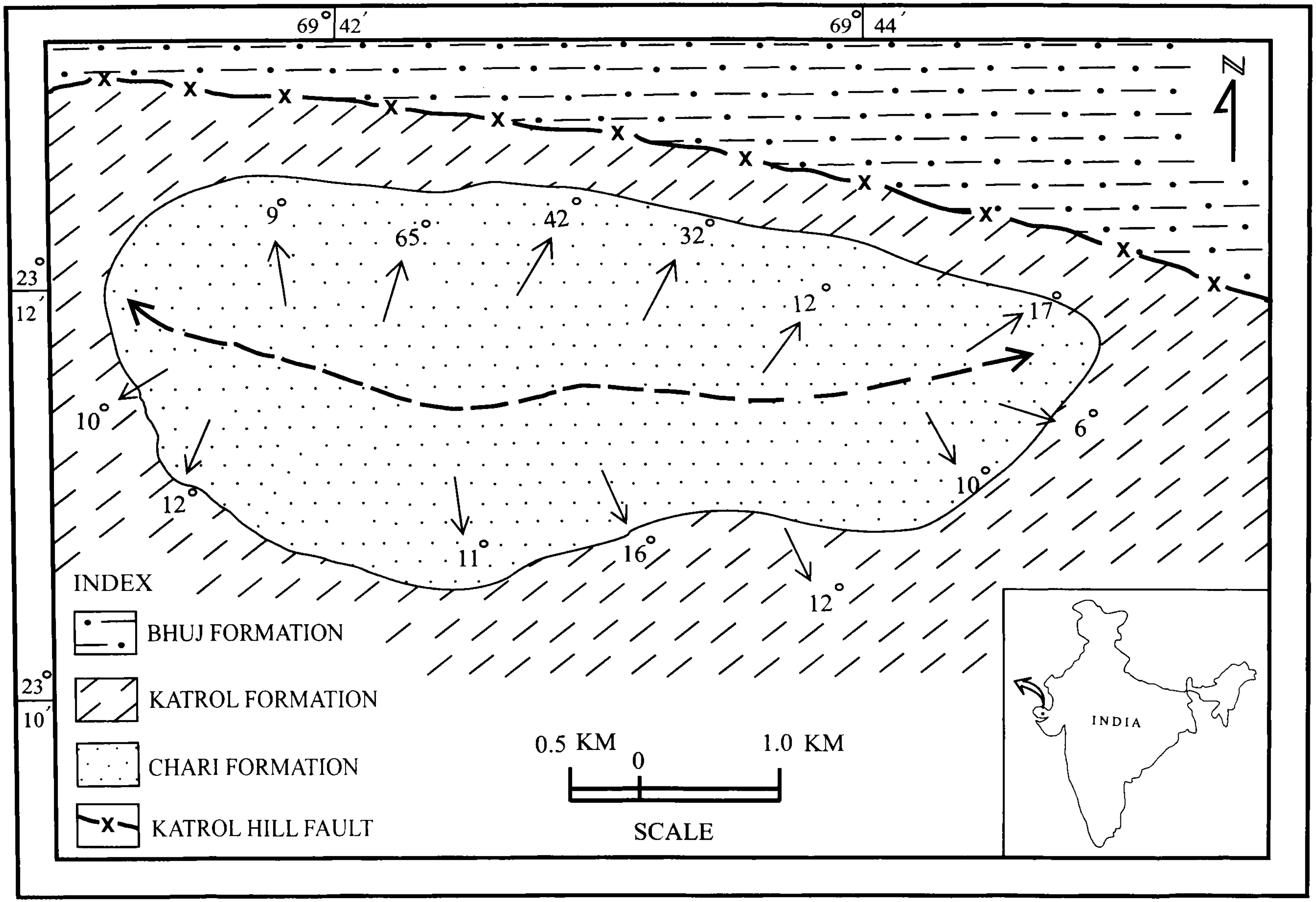


Figure 2. Geological map of Ler hill, Kachchh

It is well known that majority of the Middle and Upper Jurassic foraminiferal species of the Indian region are long ranging and truly marker species are either rare or absent during this time span. However, a good number of foraminiferal species having comparatively restricted vertical range were identified which helped in assigning a reasonably accurate age to the present sequence as well marking Callovian-Oxfordian boundary in the sequence.

The present Jurassic foraminiferal assemblage compared favorably with certain well known Jurassic assemblages of the Indian subcontinent as well as other neighboring regions of the world. The assemblage was found to exhibit Tethyan affinity and helped in testifying the earlier contention based on ammonites and other megafossils that during the Middle and Upper Jurassic times the Kachchh region, along with some other adjoining regions of the world, was part of a southwestern arm of the Tethys Sea, the Indo-Malagasy or Indo-East African seaway.

1.3 LOCATION AND ENVIRONS OF THE AREA

The Kachchh region is bounded by Little Rann in the east, Arabian Sea in the west, Gulf of Kachchh in the south and Great Rann in the north. This region is characterized by undulating topography with isolated, scattered, hillocks. The major part of the region is covered by Recent sedimentary deposits which are either alluvial or partly fluvio-marine or wind-blown. The Kachchh region belongs to semi-arid climatic zone.

The study area, *viz.*, Ler hill, located in the neighborhood of Ler village nearly 12 km SSE of Bhuj, lies between the longitudes 69° 41' 30" and 69° 45" east and latitudes 23° 10' 30" and 23° 12' 30" north (figure 2). A well exposed section on the northern side of the hill was selected for the present investigation. Ler village is connected with Bhuj by road with a few daily local bus services. The

Bhuj city is connected with air route to Delhi, Mumbai and Rajkot. It is also connected by railways and roadways to Delhi and Mumbai.

1.4 METHODS OF STUDY

1.4.1 Field Methods

After a detailed survey of the entire area, a well exposed section on the northern flank of the Ler hill was selected for sampling. Bed by bed samples from the Chari and Katrol formations exposed along the section were collected mainly on the basis of lithological variation and not at regular interval. The rocks types encountered in the Ler section are mainly shales, limestones, shelly limestone, sandstones, silty clay and conglomerates.

1.4.2 Laboratory Procedures and Techniques

A total of thirty-three surface samples were collected for the foraminiferal analysis. The samples were coarsely crushed with hammer and boiled with sodium carbonate to disintegrate them. The material was then washed through standard sieves with 35, 60, and 120 μm mesh diameter. The disintegrated material was dried in an electric oven. For particularly hard samples, the procedure was repeated as many times as required. Ten gm material from each mesh size was taken for picking the foraminiferal tests and all the tests were picked with the help of a fine sable hair brush under a stereozoom binocular microscope. Different foraminiferal species were arranged in square assemblage microfaunal slides for identification and further study.

All the photographs of the foraminiferal species for the plates were prepared with the help of a Scanning Electron Microscope (SEM), Model No. PSEM 515, Philips, Holland at Wadia Institute of Himalayan Geology, Dehradun.

CHAPTER 2

PREVIOUS INVESTIGATIONS

Jurassic marine strata are extensively developed in the Kachchh region of western India. The Jurassic sediments of this region show excellent exposures and are characterized by varied and excellently preserved invertebrate fossils, especially ammonoids, which made them famous all over the world. These fossiliferous marine strata have been under intensive stratigraphic and palaeontological investigations since 1834. A large amount of literatures is available on stratigraphic and palaeontological aspects of the Jurassic rocks of Kachchh, which helped in developing the stratigraphic sequence, age fixation of different stratigraphic units, and inter-regional correlation.

Long is the list of geological investigations on Kachchh Jurassic, beginning with Sykes (1834) who contributed in the field of stratigraphy and taxonomy of the fossils biota. It is beyond the scope of this study to discuss the findings of all the earlier investigations in this region covering different branches of geology. However, only those references which are related to the foraminifera have been discussed at some length while the rest have simply been listed.

Tewari (1957) was the first to report foraminifera from the Jurassic (Patcham 'series') rocks of Kachchh and noted the presence of *Aulotortus*, *Textularia*, *Bigenerina*, *Spiroplectammina*, and *Gaudryina* from these rocks.

Subbotina *et al.* (1960) described Jurassic foraminifera from near Lodai village on the eastern flank of Habo hill, Khawda (in the Rann of Kachchh) and from Jurassic sediments of Rajasthan. These authors described and illustrated thirty-five foraminiferal species including twelve new ones from the Chari 'series' of Kachchh and Jaisalmer 'formation' of Rajasthan and assigned a Callovian to Oxfordian age to these Jurassic deposits.

Agarwal and Singh (1961) reported fifteen foraminiferal species from near Habo hills including *Rhabdammina*, *Ammodiscus*, *Ammobaculites*, *Quinqueloculina*. *Triloculina*, *Robulus*, *Lenticulina*, *Nodosaria*, *Saraceneria*, *Vaginulina*, *Palmula*. *Nonion*, *Elphidium*, *Rotalia* and *Anomalina*. They pointed out that the presence of *Elphidium*, a Tertiary genus, in the assemblage is unusual but did not provide any reason for this anomaly.

Bhalla and Abbas (1975a, b, c; 1976a, b; 1978, 1984) published a number of papers on the foraminifera of the Jurassic sediments exposed at Habo hills, Kachchh. These authors (Bhalla and Abbas 1975a, 1976a) reported sixty-five species of foraminifera, the assemblage being dominated by family Nodosariidae which is represented by forty species and constituting 61.5% of the total population. Out of sixty-five reported species, ten were new, nine were common to those reported by earlier investigators, and the rest were reported for the first time from these rocks. During their investigation of the Jurassic foraminifera of Habo hills, Bhalla and Abbas (1975b) carried out a detail study of variation in *Lenticulina subalata* (Reuss) and concluded that this species, like other Jurassic nodosariids, is highly variable and caution must be observed while dealing with systematics of Jurassic nodosariids. Based on foraminifera, these authors (Bhalla and Abbas, 1976b) also assigned a Callovian-Oxfordian age to the studied section and suggested that the foraminiferal assemblage of the Jurassic rocks of Kachchh compares well with the Jurassic assemblages of Rajasthan, Iran, Egypt, Afghanistan, and Somalia and has Tethyan affinities. On this basis they (Bhalla and Abbas, *op. cit.*) supported the view that during Middle and Upper Jurassic times, an arm of the Tethys extended from near Iran to Madagascar which covered Afghanistan, Baluchistan, Rajasthan, Kachchh and east coast of Africa. These authors (Bhalla and Abbas, 1978) gave a detailed version of their earlier investigation of the Jurassic foraminifera from Habo hills, Kachchh. In a subsequent publication, Bhalla and Abbas (1984) presented a detailed account of the depositional environment of the Jurassic sequence exposed at Habo hills. Based on foraminiferal palaeoecology, petrography and field observations, these authors (Bhalla and Abbas, *op. cit)* suggested that the overall deposition of these sediments took place in a shallow, tectonically unstable marine basin.

Shringarpure and Desai (1975) reported a foraminiferal assemblage comprising nineteen species belonging to family Nodosariidae from Manfara Dome section of the Wagad hill block, eastern Kachchh. In a subsequent publication, Shringarpure *et al.* (1976) observed the interesting phenomenon of faunal mixing in the Mesozoic stratigraphic sequence exposed in the western Wagad region of eastern Kachchh. These workers (Shringarpure *et al.*, 1976) recovered a foraminiferal assemblage with minor amount of ostracods, bryozoans, and echinoderm spines along with microscopic plant tissues and insect skeletons of Tertiary, sub-Recent and Recent ages, associated with older Mesozoic sediments of Jurassic-Cretaceous periods. These authors (Shringarpure *et al.,* 1976) suggested that such mixing and reworking are resulted by the action of natural agencies like storm waves, stream currents, wind action, and ice rafting or even bird activities. They (Shringarpure *et al.*, 1976) further observed that some robust foraminiferal genera have undergone two previous depositional cycles before reaching their present depositional site.

Singh (1977) reported five species of genus *Epistomina* from the Banni subsurface sequence, Rann of Kachchh and recognized two biostratigraphic assemblage zones, *viz.*, *Epistomina stellicostata-E. alveolata* Assemblage-zone and *E. ventriosa-E. mosquensis* Assemblage-zone, and suggested a Late Jurassic age for these subsurface rocks. In another paper, Singh (1979) gave a detailed account of his pervious work and based on foraminifera, *Charites* spp., and ostracoda, proposed seven biostratigrpahic zones within these sediments, *viz.*, Barren Zone, *Charites-Otocythere* Assemblage Zone, *Lenticulina dilectiformis-L. carinocordatus* Assemblage Zone, *Epistomina stellicostata-E. alveolata* Assemblage Zone, *Eoguttulina liassica-Vaginulina cryptospira* Assemblage Zone. *Lenticulina-Nodosaria* Assemblage Zone, and *Lenticulina* Zone. He (Singh, 1979) observed that the beds of the sequence were accumulated in an inner- neritic environment, except the bed of *Charites-Otocythere* Assemblage Zone which was deposited in brackish to marine environment.

Bhalla and Talib (1978) reported a foraminiferal assemblage from the Chari 'series' exposed near Badi village, central Kachchh. These investigators (Bhalla and Talib, 1980) gave a detailed version of their previous findings, noted nineteen species of foraminifera dominated by the family Nodosariidae, and discussed the age and paleoecology of these rocks. Bhalla and Talib (1985a, b, c; 1991) published a series of papers on foraminifera from the Jurassic sediments of Jhurio hills, Kachchh, western India. These authors (1985a) discussed variation in the population of *Lenticulina quenstedti* recovered from Jhurio hill, Kachchh. They identified four morpho-variants of this species which were shown to continuously inter-grade into one another. In a subsequent paper, Bhalla and Talib (1985b) recovered two new species belonging to family Nodosariidae from Jurassic sediments of Jhurio hill, Kachchh, *viz., Marginulina sastryi* and *Vaginulina bhatiai*. In another publication these investigators (Bhalla and Talib, 1985c) reported fifty-three foraminiferal species from Jhurio hill, Kutch. Of these, twenty six species were recorded for the first time from the Indian region. They (Bhalla and Talib, 1985c) also briefly discussed the age and depositional environment of these sediments as well as palaeogeography of the Kachchh region during Middle and Upper Jurassic times. Bhalla and Talib (1991) gave a detailed version of their previous investigation of Jurassic foraminifera from Jhurio hill, Kachchh, western India. They described and illustrated fifty-three foraminiferal species and assigned a Callovian-Oxfordian age to the studied sequence. The foraminiferal assemblage indicates that the overall deposition of the Jurassic sequence exposed at Jhurio hill took place in a near shore, shallow marine environment which was tectonically unstable as indicated by the fluctuating shoreline. These authors (Bhalla and Talib, 1991) also discussed the palaeobiogeography of the foraminiferal assemblage, suggested a Tethyan affinity and supported the earlier view based on mega- and microfossils that during Middle and Upper Jurassic times a gulf of Tethys extended from near Afghanistan to Madagascar covering Iran, Arabia, and east coast of Africa which also covered the Kachchh region.

Bhalla and Lal (1985) reported seventeen species of foraminifera from Chari 'series' of Kaiya hill, Kachchh. The foraminiferal assemblage is dominated by the family Nodosariidae which constituted 76.44% of the total foraminiferal population.

Govindan *et al.* (1988) reported a calcareous benthic foraminiferal assemblage consisting of Epistominids, Lenticulinids, and agglutinated species belonging to genus *Dorothia* across the Jurassic-Cretaceous boundary from wells drilled in Kachchh Mainland. On the basis of foraminiferal species, these authors (Govindan *et al.* 1988) attempted to provide a finer stratigraphic subdivision and suggested that the Early Cretaceous-Late Jurassic boundary falls between the extinction level of *Epistomina caracolla* and *Epistomina stelliscotata.* Based on the highest occurrence level of zonal markers, these authors (Govindan *et al.*, 1988) divided the whole sequence into six assemblage zones, *viz.*, *Epistomina regularis-Lenticulina subalata* Assemblage Zone, *Epistomina stelligera* Zone, *Epistomina mosquensis* Zone, *Epistomina stellicostata* Zone, *Epistomina caracolla* Zone, and *Dorothia hauteriviana* Assemblage Zone.

Bhalla and Gaur (1989) recovered a new species of foraminifera belonging to family Vaginulinidae from the Jurassic (Callovian) sediments of Jumara hill, central Kachchh. The new species was named *Marginulina jumaraensis* and these authors (Bhalla and Gaur, 1989) suggested that it was capable of tolerating wide fluctuations in environmental conditions ranging from shallow, open marine to paralic environment, such as marsh or lagoon.

Mandwal and Singh (1989) reported sixteen foraminiferal species from the Patcham Formation and lower part of the Chari Formation of Jhurio hill, Kachchh. On the basis of thirteen index benthic foraminiferal species of *Garantella*, *Epistomina, Pseudomarssonella, Riyadhella, Singhamina* and *Tandonina*, these authors (Mandwal and Singh, 1989) assigned a Bathonian age to the sequence exposed in the lower part of the Jhurio hill. They (Mandwal and Singh, 1989) also demarcated the Bathonian-Callovian boundary within the exposed sequence. In a subsequent publication Mandwal and Singh (1994) reported 95 foraminiferal species from Patcham-Chari Formation of Jhurio Hill, Kachchh. Based on foraminiferal assemblages these authors (Mandwal and Singh, 1989) suggested a Bathonian-Oxfordian age for the studied sequence and also demarcated the Bathonian/Callovian and Callovian/Oxfordian boundaries in the area.

Pandey and Dave (1993) carried out detailed foraminiferal investigation from sections at different localities in Kachchh, *viz.*, Khavada *nala*, Jumara Dome, Jhurio Dome, Habo Dome, Mundhan Anticline, and Umia River. These authors identified seventy-seven species of benthic foraminifera from these sections and discussed biostratigraphy, chronostratigraphy and correlation of different stages and zones. Eleven biostratigraphic zones were proposed within the Jurassic sequence, *viz.*, *Epistomina regularis-E. ghoshi A*ssemblage Zone, *Lenticulina dilectaformis* Partial Range Zone, and *Dobrogelina rajnathi* Range Zone within Bathonian; *Lenticulina discipiens* Zone, *Tewaria kutchensis* Partial Range Zone, and *Proteonina difflugiformis - Astacolus anceps* Assemblage Zone within Callovian; *Epistomina majungaensis* Range Zone and *Epistomina majungaensis - Lenticulina bulla* Inter-biohorizon (poorly fossiliferous) Zone within Oxfordian; *Lenticulina bulla* Partial Range Zone and *Lenticulina bulla - Epistomina ventriosa* Inter-biohorizon (Barren) Zone within Kimmeridgian; and *Epistomina ventriosa* Range Zone within Tithonian.

Gaur and Singh (2000) described a foraminiferal assemblage from Jurassic strata of Nara hill, Kachchh comprising forty-four species. On the basis of foraminiferal taxa these authors (Gaur and Singh, 2000) subdivided the Callovian-Oxfordian succession of the Nara hill into four biozones, *viz.*, *Spirillina polygyrata - Lenticulina - Citharina clathrata* Assemblage Zone, *Epistomina mosquensis*

Assemblage Zone, *Flabellammina* sp. – *Triplasia emsalandensis* Assemblage Zone, and *Astacolus anceps – Epistomina alveolata* Assemblage Zone.

Gaur and Sisodia (2000) reported forty-one foraminiferal species from Jurassic sediments of Keera hill, Kachchh. These authors (Gaur and Sisodia, 2000) established four benthic foraminiferal biozones, viz., *Dentalina guembeli* - *Citharina clathrata* Assemblage Zone, *Epistomina mosquensis* Assemblage Zone, *Ammobaculites gowdai* - *Triplasia emslandensis* Assemblage Zone, *Spirillina* - *Lenticulina* Assemblage Zone, and Barren Zone.

Talib and Gaur (2005) dealt with foraminiferal paleoecology, microfacies and paleoenvironment of Middle-Upper Jurassic sequence of Jumara hills and divided the entire sequence into five palaeoecological units. They (Talib and Gaur, 2005) concluded that the overall deposition of the sequence took place in a shelf zone, which was tectonically unstable as exhibited by periodic fluctuation in the environmental conditions.

Talib and Bhalla (2006a) discussed the composition and age of the Chari Formation of Jhurio Hill. On the basis of few characteristic species of foraminifera restricted to or frequently reported from Callovian-Oxfordian strata of different parts of the world, they (Talib and Bhalla, 2006a) assigned a Callovian to Oxfordian age to the Chari Formation exposed at Jhurio Hill, Kachchh. These authors (Talib and Bhalla, 2006a) also marked the Callovian Oxfordian boundary within the sequence. In another publication, Talib and Bhalla (2006b) presented a detailed account of the affinity and palaeobiogeography of the Middle to Upper Jurassic foraminifera from Jhurio Hill, Kachchh. The Jhurio Hill foraminiferal assemblage show remarkable resemblance to those from Rajasthan and neighboring regions of the world including Afghanistan, Iran, Egypt, Somalia and Malagasy. These authors (Talib and Bhalla, 2006b) assigned a Tethyan affinity to the Jhurio Hill foraminiferal assemblage and suggested that during Middle to Upper Jurassic time foraminiferal fauna of Kachchh and the above mentioned regions were flourishing in a separate province of the Tethyan Realm, the Indo-East African Province, occupied by a southwestern arm of the Tethys.

Talib and Faisal (2006) gave a preliminary account of the occurrence of foraminifera from Fakirwari Dome, Kachchh Mainland by reporting fifty-three species which included twenty-five species recorded for the first time from the Indian region. These authors (Talib and Faisal, 2006) also briefly discussed the age, palaeoecology, and palaeobiogeography of the foraminiferal assemblage. In a subsequent publication, Talib and Faisal (2007) reported the occurrence of foraminifera in the Jurassic rocks of Ler Dome, Kachchh Mainland, recorded forty species including eighteen species reported for the first time from the Indian region. They (Talib and Faisal, 2007) also briefly discussed the age, bathymetry and palaeobiogeography of the foraminiferal assemblage.

Talib *et al.* (2007) based on foraminiferal evidence demarcated the Callovian-Oxfordian boundary in Jumara and Jhurio domes, Kachchh.

Talib and Gaur (2008) discussed the palaeobiogeography of the foraminiferal assemblage from Jumara hill, Kachchh and suggested that the foraminiferal assemblages of Kachchh region and those belonging to adjoining regions of Afghanistan, Iran, Egypt, Somalia and Malagasy exhibit a clear Tethyan affinity. These authors (Talib and Gaur, 2008) also discarded the views supporting the "Antiborial" hypothesis or the existence of an Austral Province in this region during Middle to Upper Jurassic time.

Other important references on different geological aspects of Kachchh Mesozoic are:

Grant (1837), Blanford (1867), Oldham (1869), Wynne (1869, 1872), Waagen (1871, 1873-76), Gregory (1893, 1900), Oldham (1893), Kitchin (1900, 1903), Vredenburg (1910), Spath (1924, 1927-1933), Raj Nath (1932, 1934a, b, 1938a, b, 1942), Cox (1940, 1952), Agrawal (1948, 1956, 1957), Tewari (1948), Shukla

(1953), Taylor and Oza (1954), Arkell (1956), Pascoe (1959), Poddar (1959, 1964), Lubimova *et al.* (1960), Phleger (1960), Taylor and Pathak (1960), De (1964, 1969, 1972), Mitra and Ghosh (1964), Rao (1964), Biswas and Deshpande (1968), Krishnan (1968), Ghosh (1969 a, b), Merh and Hardas (1969), Singh and Tripathi (1969), Mathur *et al.* (1970, 1971), Pal and Gangopadhyaya (1970), Biswas (1971, 1977, 1980, 1981), Sastry and Mamgain (1971), Hardas and Merh (1972), Kacchara and Kanjilal (1972), Balagopal (1973), Kanjilal and Singh (1973), Balagopal and Srivastava (1975), Desai *et al.* (1975), Gupta (1975), Bhalla (1977, 1983), Kanjilal (1978a, b), Bardan *et al.* (1979), Mitra *et al.* (1979), Singh *et al.* (1979), Deshpande and Merh (1980), Krishna (1980, 1983, 1987), Krishna *et al.* (1982, 1983), Pandey and Singh (1982), Jaitly and Singh (1983, 1984), Agrawal and Pandey (1985), Kumar (1985), Neale and Singh (1986), Bardhan and Dutta (1987), Singh (1989), Fürsich *et al.* (1992), Fürsich and Oschmann (1993), Pandey and Fürsich (1993, 1998, 2001), Bardhan *et al.* (1994), Fürsich *et al.* (1994), Jaitly *et al.* (1995), Pandey and Callomon (1995), Krishna and Ojha (1996), Khosla *et al.* (1997), Bhalla *et al.* (1998, 2000), Das *et al.* (1998), Fürsich and Heinze (1998), Das *et al.* (1999), Khosla and Jakhar (1999), Fürsich *et al.* (2000), Jain and Pandey (2000), Jaitly *et al.* (2000), Ahmad *et al.* (2001), Ahmad *et al.* (2001), Fürsich *et al.* (2001), Jaitly and Szabó (2002), Fürsich and Pandey (2003), Mukherjee *et al.* (2003), Rai (2003), Schweig *et al.* (2003), Fürsich *et al.* (2005), Jana *et al.* (2005), Khosla *et al.* (2005), Ahmad and Bhat (2006), Ahmad *et al.* (2006), Ahmad *et al.* (2006), Ahmad *et al.* (2007), Das (2007, 2008), Rudra *et al.* (2007) and Ahmad *et al.* (2008).

CHAPTER 3

GEOLOGY OF THE AREA

Jurassic was a period of world wide marine transgressions and rocks belonging to this period are well represented in Kachchh. A well exposed thick sequence of about 2000 to 3000 meters, ranging in age from Jurassic to Recent, developed in the Kachchh region which includes both marine and non-marine sediments. These rocks are widely distributed, well-exposed and richly fossiliferous including great variety of mega-invertebrates and microfossils along with some plant remains. The Jurassic rocks occupy an important place in this huge pile of sediments. The Kachchh Jurassic rocks overlie a Precambrian crystalline basement (? Erinpura Granite) exposed at Meruda hill in the great Rann of Kachchh. These rocks outcrop mainly in the form of structural domes and have been intruded by numerous sills and dykes which are part of the Deccan Trap igneous activity. Tewari (1948) postulated that the igneous activity was, perhaps, responsible for the domal appearance of the Jurassic rocks in Kachchh.

The Jurassic rocks of Kachchh crop out principally in three parallel east-west trending anticlinal ridges and an isolated rocks mass in the east near Wagad. corrugated by minor transverse folds to form irregular domes (Sastry and Mamgain, 1971). The northernmost range is nearly 161 km in length and includes a series of 'islands', *viz.*, Patcham, Khadir, Bela and Chorar. The middle range is by far the most prominent, occupying the northern margin of Kachchh region which extends for about 193 km from Lakhpat in the northwest to Habo in the east through Jara, Jumara, Nara, Keera, Chari, and Jhura. It is interesting to note that the strike of the rocks in Wagad is not in continuity with the northern and middle ranges but has an intermediate trend. The continuation of Wagad rocks is concealed beneath the alluvium of the Rann (Wynne, 1869). The southernmost anticlinal ridge is about 64 Km long, represented by Katrol-Charwar ridge, south of Bhuj. The anticlines in these three ridges are doubly plunging and owing to

Table 1

Formation	Subdivisions	Characteristic Fossils
	Deccan Traps	
	---------unconformity---------------------	
Bhuj Formation	Umia Plant Beds	*Ptilophyllum* flora
Umia Formation	Ukra Beds (calcareous shale)	*Australiceras* sp.
	Sandstones and shales	Unfossiliferous
	Trigonia Beds	*Trigonia*
	Umia Ammonite Beds	*Virgatosphinctes* sp.
Katrol Formation	Upper Katrol Shale	*Hildoglochiceras*
	Upper Katrol Sandstone	mainly unfossiliferous
	Middle Katrol Sandstone	*Torquatisphinctes* sp. and *Katroliceras*
	Lower Katrol Beds	ammonites
	Belemnites Marl of Jurun	*Belemnites*
	Kantkote Sandstone	*Euapidoceras*, *Taramelliceras* sp.
Chari Formation	Dhosa Oolite	*Mayaites*, *Epimayaites*
	Athleta Beds	*Metapeltoceras*, *Peltoceras* and *Reineckeites*
	Anceps Beds	*Kinkeliniceras*, *Hubertoceras* sp., *Indosphinctes* sp.
	Rehmanni Beds	*Reineckeia tyranniformis*, *R. rehmanni*
	Macrocephalous Beds	*Macrocephalites*, *Dolikephalites*
Patcham Formation	Coral Beds	*Macrocephalites*, *Sivajiceras*, *Procerates*
	Shelly Limestone	*Macrocephalites* sp.
	Kaur Bet Beds	*Corbula lyrata*, *Protocardia*, *Pseudotrapezium*
	----------unconformity----------------------	
	Precambrian Basement (not exposed)	

Table 1. Succession of Jurassic rocks of Kachchh (after Kumar, 1985)

quaquaversal nature of dips stand out as isolated domes with an east-west alignment. The domes are very well developed in all the three ridges and Ler hill is included in the southernmost ridge, south of Bhuj. In all the three anticlinal ridges, the northern limbs are steeper that the southern flanks.

There are four major faults in the Kachchh region running in an east-west direction (*fide* Poddar, 1959). The first of these faults lies close to the north of northern series of islands in the Rann of Kachchh. The second fault passes through Banni, eastern Kachchh. The third fault traverses through the northern part of the Kachchh Mainland and the last fault stretches along the Katrol-Charwar ridge, south of Bhuj, passing along the northern flank of the Ler Hill.

3.1 REGIONAL STRATIGRAPHY

The Kachchh Jurassic overlies a Precambrian crystalline basement and has been intruded by various sills and dykes, which are part of the Deccan Trap igneous activity. Wynne (1872) was the first to give a comprehensive account of the stratigraphy of Kachchh. Based on physical differences, the Jurassic beds were divided into lower marine and upper non-marine units which he designated as the Lower Jurassic and Upper Jurassic formations respectively. Stoliczka (*fide* Khosla *et al.,* 1997) classified the entire Mesozoic succession into four formations in ascending order, *viz.*, 'Putchum' (= Patcham), 'Charee' (= Chari), 'Katrol' and 'Oomia' (= Umia). Following him, a number of classifications were proposed by Waagen (1873-76), Oldham (1893), Vredenburg (1910), Rajnath (1927-1932, 1942), Spath (1933), Agrawal (1956), Poddar (1959) Biswas (1971, 1977), Sastry and Mamgain (1971), Kumar (1985), and others. However, for the purpose of the present study, the classification proposed by Sastry and Mamgain (1971) which is adapted and modified by Kumar (1985), with certain modifications in ages as a result of recent researches, has been followed (Table 1). This classification is based on extensive research and is widely accepted by the geoscientists of the country. According to this classification the Mesozoic succession of Kachchh is divided into five formations, *viz.*, Patcham, Chari, Katrol, Umia, and Bhuj in ascending order, ranging in age from Bathonian to post-Aptian. The marine Jurassic rocks are confined to the lower portion of the Umia Formation while the remaining part of the succession belongs to the Lower Cretaceous.

3.1.1 Patcham Formation

Patcham Formation is the oldest Formation of Kachchh Jurassic sequence and was named after the Patcham 'island' in the Rann of Kachchh where the rocks of this formation are well exposed. The name Patcham was proposed by Waagen (1873-76).

The basal part of the Patcham Formation is Kaur Bet Beds which comprises sandstones and limestones with some shale bands. This formation supports a rich fauna of Bathonian pelecypods such as *Corbula lyrata* Sowerby, *Protocardia*, *Pseudotrapezium*, etc. Beside these, few corals, ammonites, and plant fossils have also been reported. Kaur Bet Beds are followed by Shelly Limestone and Patcham Coral Beds which are composed of limestone, shale and marls and have yielded a rich assemblage of corals, brachiopods, peleycpods and ammonites, including the characteristics fossils *Macrocephalites triangularis*, *Sivajiceras congener*, and *Procerates*, etc. The Patcham formation represents neritic facies of transgressive sea and comprises about 300 meters thick strata which are best exposed in the Patcham, Khadir and Bela islands of the Great Rann of Kachchh. The presence of *Macrocephalites triangularis* and *Sivajiceras congener* suggests a Callovian age for these beds. However, the recent discovery of Late Bajocian ammonite *Leptosphinctes* from Patcham island by Jaitly and Singh (1983) suggests the extension of the lower age limit of the Patcham Formation to Bajocian.

3.1.2 Chari Formation

The Chari Formation succeeds the Patcham Formation, driving its name from the village Chari, a famous fossils locality about 50 km west-north-west of Bhuj. The name was first introduced by Stoliczka (Ms. Report) and Waagen (1873-76) popularized it in the literature. This formation is about 400m thick and the sediments comprise sandy limestone, marls, calcareous and sandy shales, calcareous sandstone, and oolitic limestones which have yielded rich and varied micro- and megafaunal assemblages, especially ammonites, cephalopods along with some brachiopods and pelecypods. It has been divided into five subdivisions commencing with the *Macrocephalus* Beds which yielded a rich collection of *Macrocephalites macrocephalus*. On the basis of ammonites, Sastry and Mamgain (1971) further categorized these beds into Upper, Middle and Lower. These beds mostly comprise limestones, intercalated shales, shales with ferruginous nodules and limestones containing iron-coated, calcareous, oolitic grains with golden colour (Golden Oolite) at the top. The common fossils of these beds are *Macrocephalites macrocephalus, Dolikephalites, Indocephalites diadematus* (Waagen), pelecypods (*Nucula* and *Astrate*) and some belemnites. Overlying this subdivision is the Rehmani Beds which comprises yellow limestone, with the characteristic fossils *Reineckeia rehmanni* (Oppel) and *Reineckeia tyranniformis*. Following these beds are the Anceps Beds containing sandy calcareous shales in the lower part and yellow limestones in the upper part with characteristic fossils *Indosphinctes* sp., *Kenkeliniceras, Hubertoceras* sp., and *Terebratula* and Cephalopods in abundance. The succeeding Athleta Beds mainly consist of light gray shales with bands of white, yellow or brown limestone. *Ammonites (Peltoceras) athleta* is the characteristics fossil along with abundant *Metapeltoceras* and *Reineckeites*. In addition, numerous species of pelecypods, cephalopods, and some fish remains have also been observed. The Dhosa (=Mebha) Oolite is the topmost subdivision of the Chari Formation which is recognized as an important stratigraphic marker as the beds are mainly composed of green, reddish or brown oolitic limestones. These sediments yielded an abundance of cephalopod fauna with *Mayaites, Epimayaites, Peltoceratoides, Euaspidoceras, Dhosaites*, etc., as well as pelecypods and terebratulids.

The total thickness of the Chari Formation is estimated to be 336 meters and the age assigned by earlier workers from Lower Callovian to most probably Lower Oxfordian of European stratigraphic equivalents (*fide* Bhalla, 1983).

3.1.3 Katrol Formation

Overlying the Chari Formation is the Katrol Formation, named after the Katrol hills, south of Bhuj where the rocks of this formation display excellent outcrops (Stoliczka, MS report). The Katrol Formation comprises shallow marine succession of shales, limestones, sandstones and grits with lenticular beds of gypseous sandy shales. Waagen (1973-76) brought the term into literature.

Katrol Formation has been divided into six sub-division, *viz.*, Kantkote Sandstones, Belemnites Marls of Jurun, Lower Katrol Beds, Middle Katrol Red Sandstone, Upper Katrol Sandstone, and Upper Katrol Shale in ascending order. The lowermost, Kantkote Sandstone comprises grey or pinkish shale in the lower part and fine to coarse sandstones in the upper part with abundant ammonites, e.g., *Euapidoceras*, *Taramelliceras* sp., etc. The presence of *Trigonia smeei* indicates an Upper Oxfordian age for the subdivision. The succeeding Belemnite Marls of Jurun contain mostly marls with belemnites, e.g., *Hibolites* spp. It is overlain by Lower Katrol Beds comprising shales, sandstones and marls with abundant ammonites and cephalopods at the base. For the first time, phylloceratids are abundantly found and the assemblage also comprises a large number of Oppeliids (Bhalla, 1983). The overlying brown and red iron-stone of the Middle Katrol Sandstone has prolific *Katroliceras* and *Torquatisphinctes* sp. The Upper Katrol Sandstones consist of unfossiliferous sandstones with doubtful record of *Aulacosphinctoides meridionalis* Spath and probably belong to Late Kimmeridgian. The overlying topmost division of Katrol Formation is Upper Katrol Shales (= Narha and Gajansar Beds) which is composed of gritty sandstones with several Portlandian fossils, i.e., *Virgatosphinctes*, *Hildoglochiceras*, *Aulacosphinctes* and *Trigonia*. *Haploceras elimatum* (Oppel) is the most common fossil in this bed (*fide* Bhalla, 1983).

Katrol Formation has a total thickness of about 750 meters and the faunal evidence suggests that this formation ranges from Upper Oxfordian to Portlandian of European equivalents (Sastry and Mamgain, 1971).

3.1.4 Umia Formation

The youngest formation of Jurassic succession of Kachchh is Umia Formation which rests over the Katrol Formation and drives its name from the village Umia in western Kachchh (Stoliczka, MS report). The main rock types of this formation are white, pale-brown, sometimes variegated sandstones with subordinate ferruginous, hard, black or brown grit and a thin band of shales of mixed rock facies of marine and continental origin. Lithologically, the rocks belonging to this formation are similar to the Gondwana rocks of the Peninsula. (*fide* Bhalla, 1983).

Umia Formation begins with the Umia Ammonites Bed which contains sandstones and shales with conglomerates along with an abundance of ammonites, the fauna being dominated by *Virgatosphinctes,* particularly *V. denseplicatus* (Waagen). The succeeding Trigonia Beds consist of sandstones with characteristics fossils *Trigonia crassa* Kitchin and *T. ventricosa* Krauss. Following this are the unfossiliferous shales and sandstones. The topmost bed of Umia Formation is Ukra Beds which comprise about 23 meter thick succession of greenish sandstone, calcareous shales, grits and marls with characteristic fossils *Australiceras* sp., *Cheloniceras*, and *Tripocium* of Aptian age.

The total thickness of Umia Formation is estimated to be about 525 meters (Kumar, 1985). Sastry and Mamgain (1971) considered the age of Umia Formation, including Ukra Beds, ranging from Tithonian to most probably Neocomian but few workers assigned an Aptian age to Ukra Beds of Umia Formation.

3.1.5 Bhuj Formation

The top most Formation of Mesozoic succession in the Kachchh region has been designated as Bhuj Formation which contains sandstones, glauconitic sandstones, and shales with abundant plant fossils (Filicales, Cycadophytes, Conifers and Incertae). The saurian remains of *Plesiosaurus indica* has also been reported from

Figure 3

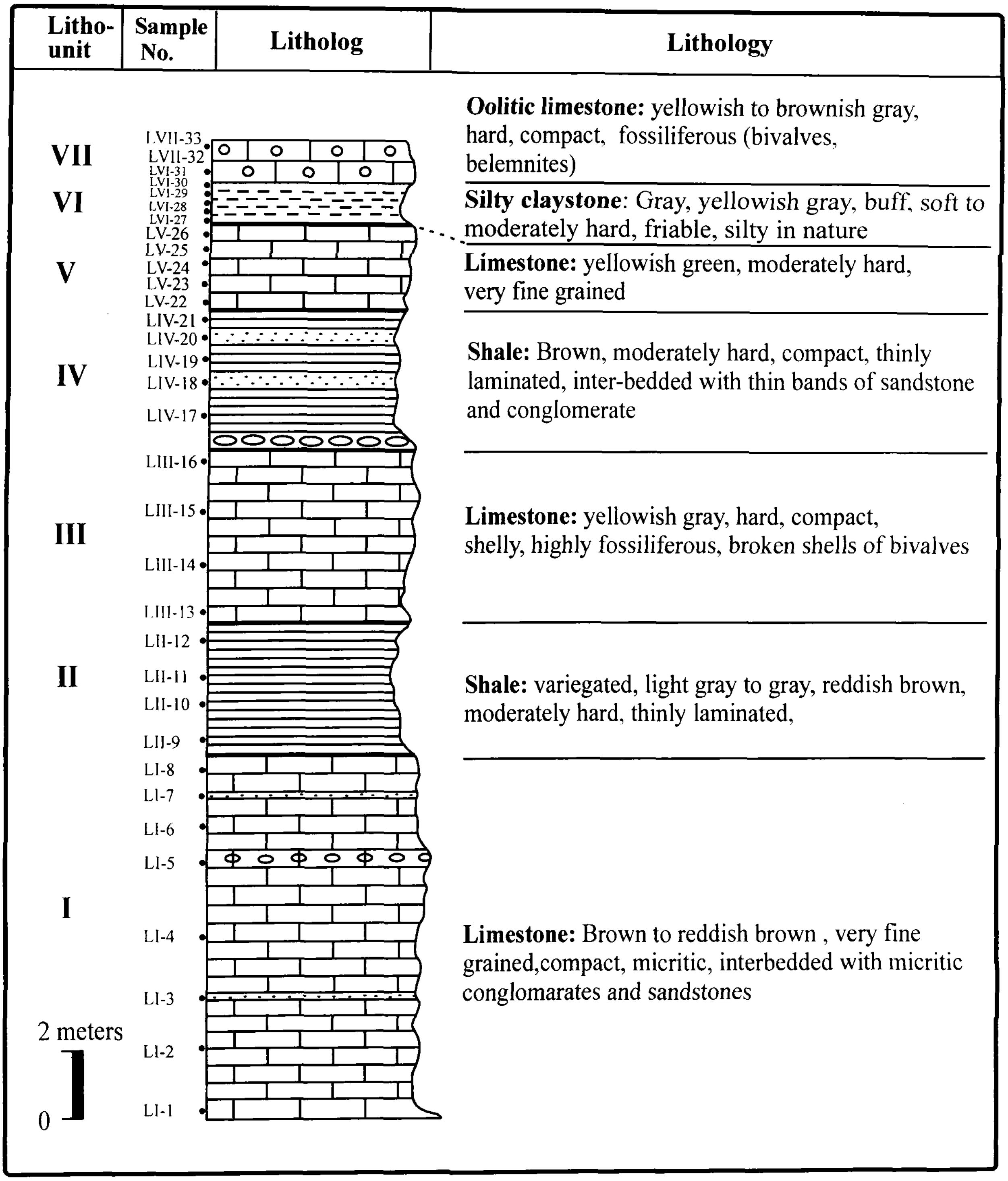


Figure 3. Litholog of Middle-Upper Jurassic sequence exposed at Ler, Kachchh, showing sample locations

Bhuj Formation. The characteristic plant fossil of these beds is *Ptillophylum* of post-Aptian (Upper Gondwana) age.

3.2 STRATIGRAPHY OF LER HILL

The Ler hill is one of the prominent domes located south of Bhuj in the Kachchh region and is named after the village Ler, situated around 200m northeast of Ler hill. The Ler hill stretches for about seven km in length and four km in width, covering an area of about 28 sq. km. It is a doubly plunging anticline and due to quaquaversal nature of dips, has assumed the shape of a dome. Like all other domes in the Kachchh region, the dip of the beds in this dome is relatively gentle towards south and comparatively steep towards north. There are several minor faults passing through this hill but dislocation of the beds was not observed.

For the present investigation a well-exposed section was selected along the eastern margin of the Ler hill. The Chari and Katrol formations are well exposed in this section while Patcham and Umia formations are missing (figure 3). Of the two formations, Chari displays the best developed sequence. In the present investigation, Katrol Formation has been excluded because only "leaked" foraminifera of post-Jurassic age were found in these sediments.

3.2.1 Chari Formation

The rocks of Chari Formation are extensively developed and well exposed at Ler hill and are best seen in the present section. The present section exposes about 31 meters thick sequence of rocks belonging to Chari Formation. The base of Chari Formation is not exposed in the section.

In the Ler section the rocks of Chari Formation consist of arenaceous to argillaceous sediments, consisting of limestones, shales, conglomerates, sandstones, and silty claystone. Generally, limestones are brown to reddish brown, yellowish green, yellowish gray, hard, compact, and fossiliferous (Litho-unit III) and shales are brown, light gray to gray, variegated (Litho-unit II), moderately hard, thinly laminated, and inter-bedded with thin bands of sandstone and conglomerate (Litho-unit IV). Limestones and shales are the dominating rock types in the Chari Formation of Ler hill. Sandstones are mostly gray to yellowish gray, fine to medium grained and occur as thin bands in between limestone beds (Litho-units I and IV).

3.2.2 Katrol Formation

The younger formation of Jurassic sequence exposed in Ler area is Katrol Formation. The rocks belonging to Katrol Formation are well exposed in the Ler hill. The rock types are generally hard, reddish to brown colored, ferruginous, medium to coarse grained sandstone. They are generally unfossiliferous and are covered by a thick blanket of alluvium.

CHAPTER 4

SYSTEMATIC MICROPALAEONTOLOGY

4.1 CLASSIFICATION

A number of classifications of foraminiferida have been proposed by different workers from time to time. However, the recent foraminiferal classification proposed by Loeblich and Tappan (1988) has been followed in the present work as it is the most logical and workable classification till this date. This classification embraces nearly all the prominent diagnostic characters as well as phylogenetic relationships of foraminiferida and is widely accepted by researchers all over the world.

In the present work, the different genera are arranged in accordance with the classification proposed by Loeblich and Tappan (1988) whereas the different species within a single genus are arranged in alphabetical order. References concerning important changes in generic names or species closely resembling ours have only been cited. In order to avoid repetition, suffix *et syn.* have been added to the references which contain satisfactory synonymies.

4.2 REPOSITORY OF TYPE MATERIAL

All photographed specimens have been housed in the micropalaeontological collection of the Department of Geology, Aligarh Muslim University, Aligarh and are prefixed with the word AMUGD Cat. No.

4. 3 SYSTEMATIC DESCRIPTIONS

Order FORAMINIFERIDA Eichwald, 1830

Suborder TEXTULARIINA Delage and Hérouard, 1896

Superfamily ASTRORHIZACEA Brady, 1881

4.3.1 Family SACCAMMINIDAE Brady, 1884

Subfamily SACCAMMININAE Brady, 1884

Genus SACCAMMINA Carpenter, 1869

Saccammina cf. *S. franconica* Ziegler

Plate IV, figure 1

1959 - *Saccammina franconica* ZIEGLER, p. 88, pl. 2, fig. 22.

1976 - *Saccammina* cf. *S. franconica* Ziegler.- SOUAYA, p. 264, pl. 7, fig. 6.

Description: Test small, sub-rounded in outline, slightly compressed; aperture rounded on a short conical neck; wall coarsely agglutinated, firmly cemented; surface rough.

Dimensions (in mm): Major diameter 0.16-0.39, minor diameter 0.15-0.24, thickness 0.06-0.28.

Remarks: Specimens of *Saccammina* are abundant in the present material which could be compared with *Saccammina franconica* Ziegler. The present forms are similar to those described by Souaya (1976) from Canada.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 462.

Superfamily HORMOSINACEA Haeckel, 1894

4.3.2 Family HORMOSINIDAE Haeckel, 1894

Subfamily REOPHACINAE Cushman, 1910

Genus REOPHAX de Montfort, 1808

Reophax metensis Franke

Plate IV, figure 2

1936 - *Reophax metensis* FRANKE, p. 19, pl. 1, figs. 17a, b.

1955 - *Reophax metensis* Franke.- TAPPAN, p. 36, pl. 7, figs. 11-14.

1958 - cf. *Reophax metensis* Franke.- SAID and BARAKAT, p. 239, pl. 3, fig. 6.

1989 - *Reophax metensis* Franke.- NAGY and JOHANSEN, p. 343, pl. 1, figs.1-25; pl. 2, figs.1-15.

1991- *Reophax metensis* Franke.- NAGY and JOHANSEN, p.19, pl. 1, figs. 22-29.

Description: Test small to large; chamber onion-shaped to elongate, tapering at both ends in some specimens; sutures appear to be deeply depressed; periphery lobulate; aperture terminal, rounded, at the end of a long, gently conical neck; wall moderately agglutinated; surface rough.

Dimensions (in mm): Length 0.27-0.81, width 0.2-0.52, thickness 0.09-0.29.

Remarks: A large population of *Reophax metensis* Franke with only the last chamber as well as remains of the preceding chamber was obtained from the present material. The Indian specimens described here are similar to those described and illustrated by Nagy and Johansen (1989, 1991) from Jurassic of North Sea. A detailed study of variation in *R. metensis* was carried out by Nagy and Johansen (1989). Said and Barakat (1958) compared their form with *R. metensis*. Like North Sea specimens, the Indian forms show sign of breakage at the proximal end and the single chambered, onion-shaped tests are also common.

Some of our forms taper at both the ends while others are flask-shaped. These authors (Nagy and Johansen, 1989) reported two to three or a maximum of six chambers in *R. metensis* and our forms come well within the variation rage of this species as illustrated by Nagy and Johansen (1989).

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 463.

Reophax multilocularis Haeusler

Plate IV, figure 3

1890 - *Reophax multilocularis* HAEUSLER, p. 28, pl. 3, figs. 9-11, 26.

1991- aff. *Reophax multilocularis* Haeusler.- BHALLA and TALIB, p. 93, pl. I, fig.14, *et syn.*

1991 - *Reophax multilocularis* Haeusler.- NAGY and JOHNSEN, pp.19-20, pl. 2, figs. 4-5.

1995 - *Reophax multilocularis* Haeusler.- NEAGU and NEAGU, pl. 1, figs. 18-22.

Description: Test small, elongate, somewhat compressed, uniserial, slightly tapering, somewhat inflated; chambers seven to eight in number, increasing gradually as added, broader than high; sutures distinct, transverse, faintly depressed; periphery nearly lobulate; aperture indistinct, terminal, appears to be a slit like opening, without neck; wall coarsely agglutinated; surface rough.

Dimensions (in mm): Length 0.29-0.36, width 0.09-0.13, thickness 0.06-0.07.

Remarks: A few specimens of *Reophax multilocularis* Haeusler were encountered in our material which are similar in nearly all the characters to those described by Gordon (1967) and Kalantari (1969) From the Jurassic of Scotland and Iran respectively. Our forms also exhibit similarities to those figured by Neagu and Neagu (1995) from the Upper Jurassic sediments of Romania but differ in having somewhat constricted sutures. This species was first described by Haeusler (1890), who mentioned twenty-two to twenty-five chambers whereas Cifelli (1959), Gordon (1967), Kalantari (1969), and Nagy and Johansen (1991) described it with much less number of chambers, ranging from four to nine. Our specimens also show lesser number of chambers like the, English, Iranian and North Sea forms.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 464.

Reophax aff. *R. scorpiurus* Montfort

Plate IV, figure 4

1936 - *Reophax scorpiurus* Montfort.- FRANKE , p. 19, pl. 1, fig. 18.

1958 - *Reophax scorpiurus* Montfort.- SAID and BARAKAT, p. 239, pl. 4, fig. 9.

Description: Test medium, elongate, uniserial, very slightly tapering; four-five slightly inflated chambers, increasing gradually in size as added; sutures distinct, depressed, almost straight; aperture indistinct, appears to be simple, terminal, rounded; wall agglutinated; surface rough.

Dimension (in mm): Length 0.42-0.60, width 0.22-0.36, thickness 0.15-0.19.

Remarks: A few specimens of *Reophax* were found in the present material which show affinities with *Reophax scorpiurus* Montfort, described by Said and Barakat (1958) from Jurassic rocks of Sinai, Egypt. Indian forms differ form the Egyptian specimens in having a large number of chambers.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 465.

Reophax sundancensis Loeblich and Tappan

Plate IV, figure 5

1950a - *Reophax sundancensis* LOEBLICH and TAPPAN, p. 41, pl. 11, fig. 1.

Description: Test small, elongate, slightly tapering, uniserial; four to five chambers, slightly inflated; sutures distinct, depressed, oblique to test axis; aperture simple, terminal, rounded, at the end of a short neck; wall moderately agglutinated; surface rough.

Dimensions (in mm.): Length 0.30-0.36, width 0.1-0.15, thickness 0.04-0.09.

Remarks: Abundant specimens of *Reophax sundancensis* were recovered from the present material which are similar to those described originally by Loeblich and Tappan (1950a) from the Jurassic rocks of North America. However, the Indian forms differ in having slightly oblique sutures and somewhat less inflated chambers.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 466.

Superfamily LITUOLACEA de Blainville, 1827

4.3.3 Family LITUOLIDAE de Blainville, 1827

Subfamily AMMOMARGINULININAE Podobina, 1978

Genus AMMOBACULITES Cushman, 1910

Ammobaculites cobbani Loeblich and Tappan

Plate IV, figure 6

1950a - *Ammobaculites cobbani* LOEBLICH and TAPPAN, pp. 41- 42, pl. 11, figs. 9a-13.

1991 - *Ammobaculites cobbani* Loeblich and Tappan, BHALLA and TALIB, p. 94, pl. I, fig.18, *et syn.*

Description: Test small, flattened; early portion planispiral, involute, closely coiled, coiling slightly off-center, nearly trochospiral in appearance, moderately umblicate, coiled portion covering one third of the test, with four triangular chambers, increasing gradually in size as added; sutures of early portion radial, slightly thickened, depressed, gently curved; later portion uniserial, with two broad, low, chambers, enlarging slightly in height and width as added, last chamber about twice the height of the previous one; sutures of uniserial portion distinct, thickened, depressed, transverse; periphery slightly lobulate; aperture terminal, rounded; wall agglutinated; surface rough.

Dimensions (in mm): Length of test 0.30-0.36, length of uncoiled portion 0.15-0.17, width of uncoiled portion 0.13-0.15, diameter of coiled portion 0.13-0.20.

Remarks: A few specimens of *Ammobaculites cobbani* were recovered from the present material. Our forms come well within the variation range of this species described originally by Loeblich and Tappan (1950a) from the Jurassic sediments of North America. The present forms are also similar to those described by Bhalla and Talib (1991) from the Callovian-Oxfordian sediments of, Jhurio hill, Kachchh. Our forms are rather coarsely agglutinated with rough surface.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 467.

Ammobaculites fontinensis (Terquem)

Plate IV, figure 7

1870 - *Haplophragmium fontinensis* TERQUEM, p. 337, pl. 24, figs. 29-30a, b.

1958 - *Ammobaculites fontinensis* (Terquem).- SAID and BRAKAT, p. 241, pl. 2, fig. 2; pl. 3, fig. 9.

1969 - *Ammobaculites fontinensis* (Terquem).- KALANTRI, pp. 21-22, pl. 7, fig. 15; pl. 8, figs. 3, 6.

1981 - *Ammobaculites fontinensis* (Terquem). - COLEMAN, p. 112, pl. 6.2.1, fig. 3.

1991 - *Ammobaculites fontinensis* (Terquem). - BHALLA and TALIB, p. 95, pl. I, fig.11.

1991 - *Ammobaculites fontinensis* (Terquem). - NAGY and JOHANSEN, pp. 20-21, pl. 2, figs., 13-16.

2001 - *Ammobaculites fontinensis* (Terquem). - NAGY, FINSTAD, DYPRIK and BREMER, pl. 1, fig. 8.

Description: Test medium, compressed; early portion planispiral, evolute, closely coiled, umblicate, with an open umblical area, covering about half the length of the test, about two volutions, with six triangular chambers in outer whorl , increasing gradually in size as added; later portion uniserial, with a two chambers, last chamber more inflated than the preceding one; sutures distinct, depressed, slightly curved in early portion, later transverse; aperture terminal, rounded; wall coarsely agglutinated; surface rough.

Dimensions (in mm): Length of test 0.36-0.39, length of uncoiled portion 0.15-0.17, width of uncoiled portion 0.13-0.15, diameter of coiled portion 0.15-0.21.

Remarks: A few specimens of *Ammobaculites fontinensis* (Terquem) were obtained from the present material which are similar to those described by Said and Barakat (1958) and Kalantari (1969) from Jurassic sediments of Egypt and

Iran respectively. Our forms also show similarities to those described by Coleman (1981) from Bajocian-Callovian of England, by Bhalla and Talib (1991) from Callovian-Oxfordian of Jhurio hill, Kachchh, by Nagy and Johansen (1991) from Jurassic of northern North Sea, and by Nagy *et al.* (2001) from Callovian of northeast Scotland. Nagy and Johansen (1991) considered *Haplophragmoides barrowensis* illustrated by Tappan (1955) as a junior synonym of this species.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 468.

Ammobaculites hagni Bhalla and Abbas

Plate IV, figure 8

1978 - *Ammobaculites hagni* BHALLA and ABBAS, p. 171, pl. 3, figs. 1-3.

Description: Test small, elongate, slightly compressed; initial part planispiral, later portion rectilinear, uniserial; planispiral portion with three chambers, increasing gradually in size as added; sutures of planispiral portion distinct, radial, slightly depressed, more or less curved; uncoiled part with five chambers, enlarging gradually as added; sutures of uncoiled portion distinct, slightly depressed, simple, gently arched; periphery lobulate, irregular ; aperture indistinct, appears to be a simple, terminal, rounded opening; wall arenaceous consisting of medium grained quartz; surface rough.

Dimensions (in mm): Length of test 0.30-0.34, length of uncoiled portion 0.19-0.24, width of uncoiled portion 0.12-0.16, diameter of coiled portion 0.09-0.13.

Remarks: A few specimens of *Ammobaculites hagni* were recovered from the present material which are almost similar to those described originally by Bhalla and Abbas (1978) from the Callovian--Oxfordian sediments of Habo hills, Kachchh.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 469.

Ammobaculites subcretaceous Cushman and Alexander

Plate IV, figure 9

1930 - *Ammobaculites subcretaceous* CUSHMAN and ALEXANDER, p. 6, pl. 2, figs. 9-10.

1991 - *Ammobaculites subcretaceous* Cushman and Alexander. - BHALLA and TALIB, P. 95-96, pl. I, fig. 10.

1993 - *Ammobaculites subcretaceous* Cushman and Alexander.- PANDEY and DAVE, p. 123, pl. 1, figs. 6-8.

Description: Test medium, compressed; early portion closely coiled, involute, with a shallow depression in the centre of coiled portion, six chambers, triangular, increasing gradually in size as added; later portion uniserial, with two rectilinear chambers; sutures of coiled portion indistinct; sutures of uncoiled portion distinct, slightly depressed, oblique to test axis; aperture indistinct, appears to be terminal, rounded; wall coarsely agglutinated; surface rough.

Dimensions (in mm): Length of test 0.59-0.64, length of uncoiled portion 0.21-0.24, width of uncoiled portion 0.15-0.22, diameter of coiled portion 0.15-0.16.

Remarks: Two specimens of *Ammobaculites subcretaceous* were obtained from the present material which resemble to those described by Pandey and Dave (1993) from the Jurassic rocks of Kachchh but differ in having oblique sutures and lesser number of chambers in the uncoiled portion.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 470.

Genus KUTSEVELLA Dain, 1978

Kutsevella spilota Nagy and Seidenkrantz

Plate IV, figure 10

2003 - *Kutsevella spilota* NAGY and SEIDENKRANTZ, pp. 36-38, pl. 4, figs. 1-18.

Description : Test small, flattened, sub-circular to ovoid, planispiral, evolute, tending to uncoil in later stage; chambers six to seven in final whorl, slightly elongate in early stage, later enlarging very slightly; sutures indistinct, radial, slightly depressed, almost straight; periphery entire in early portion, later lobulate; aperture indistinct, appears to be a sub-elliptical, areal opening ; wall moderately agglutinated; surface rough.

Dimension (in mm): Major diameter 0.21-0.36, minor diameter 0.18-0.25, thickness 0.06-0.09.

Remarks: A few specimens of *Kutsevella spilota* were obtained from the Kachchh material which are similar to those described originally by Nagy and Seidenkrantz (2003) from Jurassic rocks of Denmark.

These authors (*op. cit.*) mentioned that this species is distinguished by its evolute planispiral test, lobulate periphery of last formed chambers, a marked tendency to uncoil, and moderately coarse grained wall material.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 471.

Superfamily HAPLOPHRAGMIACEA Eimer and Fickert, 1899

4.3.4 Family AMMOBACULINIDAE Saidova, 1981

Genus BULBOBACULITES Maync, 1952

Bulbobaculites vermiculus Nagy and Seidenkrantz

Plate IV, figure 11

2003 - *Bulbobaculites vermiculus* NAGY and SEIDENKRANTZ, pp. 38-40, pl. 5, figs. 1-21.

Description: Test small, elongate, initial part streptospirally coiled, later portion uniserial; coiled portion with three chambers; uncoiled portion with three to five rectilinear chambers; diameter of initial coil larger than the diameter of first formed chamber of uniserial portion, diameter of last chamber slightly larger than the diameter of coiled portion; sutures distinct, depressed, constricted, almost straight in uncoiled portion; aperture terminal radiate; wall moderately agglutinated; surface somewhat rough.

Dimensions (in mm): Length of test, 0.29-0.35, length of uncoiled portion 0.22-0.26, width of uncoiled portion 0.11-0.14, diameter of coiled portion 0.01-0.15.

Remarks: few specimens of *Bulbobaculites vermiculus* were recovered from the present material which are similar to those described originally by Nagy and Seidenkrantz (2003) from the Jurassic deposits of Denmark. However, the Indian forms differ in having a slightly larger coiled portion. The diagnostic features of this species as described by these workers (*op. cit.*) are smaller initial portion with streptospiral to irregular coiling and the diameter of first chamber of the uncoiled portion being smaller than the diameter of the coiled part.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 472.

4.3.5 Family HAPLOPHRAGMIIDAE Eimer and Fickert, 1899

Genus HAPLOPHRAGMIUM Reuss, 1860

Haplophragmium kutchensis Pandey and Dave

Plate IV, figure 12

1993- *Haplophragmium kutchensis* PANDEY and DAVE, p. 192, pl. 2, figs. 8-12.

Description: Test small, elongate, compressed; early portion streoptospirally coiled with three chambers; later part rectilinear, compressed, fairly expanding, with four chambers, increasing gradually in height and width as added; sutures rather indistinct, depressed, slightly curved to arcuate; aperture indistinct, appears to be terminal rounded; wall coarsely agglutinated; surface rough.

Dimensions (in mm): Length of test 0.34, length of uncoiled portion 0.26, width of uncoiled portion 0.18, diameter of coiled portion 0.12.

Remarks: A solitary specimen of *Haplophragmium kutchensis* was found in the present material which resembles to those described originally by Pandey and Dave (1993) from the Jurassic/Cretaceous boundary in the Kachchh region. Our form exhibits a less prominent streoprospiral coil than the original forms and lesser number of chambers in the uniserial portion.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 473.

Superfamily SPIROPLECTAMMINACEA Cushman, 1927

4.3.6 Family SPIROPLECTAMMINIDAE Cushman, 1927

Subfamily SPIROPLECTAMMININAE Cushman, 1927

Genus SPIROPLECTAMMINA Cushman, 1927

Spiroplectammina sp. indet

Plate IV, figure 13

Description: Test small, elongate, compressed; early portion planispiral, later uncoiled, biserial; chambers of planispiral portion indistinct, appear to be four in number; biserial portion with a total of five chambers chambers broader than high, increasing gradually in size as added; sutures of planispiral portion indistinct, radial, depressed; sutures of biserial portion distinct, slightly depressed; aperture not visible; wall finely agglutinated; surface more or less smooth.

Dimensions (in mm): Length of test 0.30, length of uncoiled portion 0.22, width of uncoiled portion 0.21, diameter of coiled portion 0.12.

Remarks: A solitary, broken specimen of genus *Spiroplectammina* was obtained from the present material which could not be compared with any described species of the genus. However, it shows some similarities to *Spiroplectammina* sp. described by Souaya (1976).

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 474.

Superfamily TEXTULARIACEA Ehrenberg, 1838

4.3.7 Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily TEXTULARIINAE Ehrenberg, 1838

Genus BIGENERINA d'Orbigny, 1826

Bigenerina sp. indet.

Plate IV, figure 14

Description: Test small, elongate, compressed, slightly curved, early portion biserial, later abruptly becoming uniserial; twelve chambers in biserial portion, enlarging gradually in size as added, initially slightly inflated, later more inflated; two chambers in uniserial portion, strongly inflated, globular; sutures distinct, initially flush, later depressed, oblique to the long axis of test; median sutures simple, zigzag, flush in early portion, slightly depressed later; periphery slightly lobulate; aperture indistinct, appears to be terminal rounded; wall finely agglutinated; surface somewhat smooth.

Dimension (in mm): Length 0.36-0.42, width 0.09-0.12, thickness 0.06-0.80.

Remarks: A few specimens of genus *Bigenerina* were obtained from the Kachchh material which could not be compared with any known species of this genus. However, our forms resemble with the *Bigenerina* sp. described by Gordon (1967) from Callovian sediments of Scotland. This may represent a new species but more well preserved specimens are required for assigning a specific name.

Occurrence: Frequent.

Repository of type material: AMUGD Cat. No. MF. 475.

Suborder INVOLUTININA Hohenegger and Piller, 1927

4.3.8 Family INVOLUTINIDAE Bütschli, 1880

Subfamily INVOLUTININAE Bütschli, 1880

Genous TROCHOLINA Paalzow, 1922

Trocholina aff. *T. conosimilis* Subbotina and Srivastava

Plate IV, figure 15

1960 - *Trocholina conosimilis* SUBBOTINA and SRIVASTAVA *in* Subbotina *et al.*, pp. 41-42, pl. 4, figs. 5a-c.

1991- *Trocholina conosimilis* Subbotina and Srivastava.- BHALLA and TALIB. p. 104, pl. IV, figs. 11-12.

1993- *Trocholina conosimilis* Subbotina and Srivastava.- PANDEY and DAVE, p. 125, pl. 2, figs. 7-8.

Description: Test small, subconical with broad conical angle, sharp peripheral margin, trochospiral, low- spired, evolute on the convex spiral side; spherical proloculus followed by spiral, undivided, tubular second chamber, making five closely coiled whorls; sutures distinct, spiral, slightly raised; ventral side involute, almost flat; umblical area filled with calcareous material; aperture at open end of the tube; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.21, minor diameter 0.18, thickness 0.09.

Remarks: A solitary specimen of *Trocholina* was recovered from the present material. It shows affinity to *T. conosimilis* Subbotina and Srivastava (1960) from the Jurassic (Oxfordian) rocks of Kachchh. However, the present form possesses slightly raised sutures unlike the specimens described by the original authors as well as Bhalla and Talib (1991) and Pandey and Dave (1993), all described from the Jurassic sediments of Kachchh.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 476.

Suborder SPIRILLININA Hohenegger and Piller, 1975

4.3.9 Family SPIRILLINIDAE Reuss and Fritsch, 1861

Genus SPIRILLINA Ehrenberg, 1843

Spirillina polygyrata Gümbel

Plate IV, figure 16

1862- *Spirillina polygyrata* GÜMBEL, p. 214, p. 4, figs. 11a-c.

1991- *Spirillina polygyrata* Gümbel.- BHALLA and TALIB, p. 103, pl. IV, fig. 10, *et syn.*

1993- *Spirillina polygyrata* Gümbel.- PANDEY and DAVE, p. 126, pl. 3, figs. 1-2.

Description: Test small, discoidal, flattened, planispiral, evolute, compressed; globular proloculus followed by tightly coiled, tubular, undivided second chamber. consisting of five to seven whorls; spiral sutures distinct, depressed; aperture at open end of the tube; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.12-0.30, minor diameter 0.15-0.27. thickness 0.03-0.10.

Remarks: *Spirillina polygyrata* Gümbel is a famous and well established Jurassic species of *Spirillina*, first described by Gümbel (1862) from the Oxfordian sediments of Germany. The present material has yielded a large number of this species. They are similar to those described by Kalantari (1969) from the Jurassic of Iran. Our forms are also similar to those described by various workers from the Jurassic rock of Kachchh, including Bhalla and Abbas (1978), Bhalla and Talib (1991), and Pandey and Dave (1993).

The present specimens of *Spirillina polygyrata* show considerable variation in size, thickness, number of whorls, and the degree of central depression of the test.

Bhalla and Abbas (1978) made a detail study of variation and dimorphism exhibited by *S. polygyrata.*

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 477.

Suborder LAGENINA Delage and Hérouard, 1896

Superfamily NODOSARIACEA Ehrenberg, 1838

4.3.10 Family NODOSARIIDAE Ehrenberg, 1838

Subfamily NODOSARIINAE Ehrenberg, 1838

Genus LAEVIDENTALINA Loeblich and Tappan, 1986

Laevidentalina gümbeli (Schwager)

Plate V, figure 1

1865 - *Dentalina gümbeli* SCHWAGER, p. 101, pl. 2, fig. 20.

1978 - *Dentalina gümbeli* Schwager. - BHALLA and ABBAS, pp. 178-179, pl. 7, fig. 4, *et syn.*

1991 - *Dentalina gümbeli* Schwager. - BHALLA and TALIB, p. 98, pl. II, fig. 4, *et syn.*

Description: Test small, elongate, slightly curved, uniserial, chambers three in number, slightly inflated, higher than broader; sutures distinct, simple, depressed, slightly inclined, parallel to one and other, oblique to test axis; aperture distinct, terminal radiate, eccentric, placed on a short neck; wall calcareous; surface smooth.

Dimensions (in mm): Length 0.42-0.45, width 0.09-0.12.

Remarks: Two broken specimens of *Laevidentalina gümbeli*, originally described by Schwager (1865) from the Oxfordian of Germany, were recovered from the present material. This species is characterized by its variable form and irregular development (Gordon, 1965). It is an extremely variable Jurassic nodosariid and exhibits a wide range of morphological overlap. Different workers including Gordon (1965), Bhalla and Abbas (1978), and Bhalla and Talib (1991) expressed their views that different species of *Dentalina*, *viz.*, *D. gümbeli* Schwager, 1865;

D. communis d'Orbigny, 1826; and *D. pseudocommunis* Franke, 1936 are perhaps different morphovarients of the same species.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 478.

Laevidentalina aff. *L. oppeli* (Schwager)

Plate V, figure 2

1865 - *Dentalina oppeli* SCHWAGAR, p. 95, pl. III, figs. 16-17.

1963 - aff. *Dentalina oppeli* Schwagar. - ESPITALIE and SIGAL, pp. 53-54, pl. XXIV, fig. 8.

Description: Test small, elongate, slightly arcuate, uniserial, tapered, proloculus globular, with a stout basal spine; four in number, slightly inflated, increasing gradually in size as added; sutures distinct, simple, initially flushed, slightly depressed later; wall calcareous; surface smooth.

Dimensions (in mm): Length 0.36, width 0.07.

Remarks: A solitary broken specimen of the genus *Laevidentalina* was recovered from the present material which is similar to *Dentalina* aff. *D. oppeli* Schwagar, described by Espitalie and Sigal (1963) from the Jurassic sediments of Madagascar.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 479.

Genus NODOSARIA Lamarck, 1812

Nodosaria simplex (Terquem)

Plate V, figure 3

1858 - *Dentalina simplex* TERQUEM, p. 599, pl. 2, figs. 5a-b.

1958 - *Nodosaria simplex* (Terquem). - SAID and BARAKAT, p. 255, pl. 2, fig. 29; pl. 5, fig. 9.

1969 - *Nodosaria simplex* (Terquem). - KALANTARI, pp. 73-74, pl. 4, figs. 6, 15-17.

1991 - *Nodosaria simplex* (Terquem). - BHALLA and TALIB, p. 97, pl. I, fig. 4.

Description: Test small, elongate, sub-parallel, uniserial, rectilinear, almost cylindrical; chambers four in number, slightly inflated, very slowly increasing in size; sutures simple, transverse, depressed; aperture indistinct, appears to be terminal radiate; wall calcareous, perforate; surface smooth.

Dimensions (in mm): Length 0.21-0.27, width 0.09-0.10.

Remarks: A solitary, broken specimen of *Nodosaria simplex* (Terquem) was recovered from the present material. Our specimen closely resembles the forms described by Said and Barakat (1958) and Kalantari (1969) from the Jurassic sediments of Egypt and Iran respectively. *Nodosaria simplex* (Terquem) described by Bhalla and Talib (1991) from Jhurio hill Kachchh somewhat resembles our form but the last chamber of their specimens is higher than broad and increases rather rapidly.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 480.

Genus PSEUDONODOSARIA Boomgaart, 1949

Pseudonodosaria vulgata (Bornemann)

Plate V, figure 4

1854 - *Glandulina vulgata* BORNEMANN, p. 31, pl. 2, figs. 1a, b-2a, b.

1988 - *Pseudonodosaria vulgata* (Bornemann). - OLSZEWSKA and WIECZOREK, pl. 1, fig. 25.

1981 - *Pseudonodosaria vulgata* (Bornemann). - BARNARD, CORDEY and SHIPP, p. 410, pl. 3, figs, 9, 11.

1991 - *Pseudonodosaria vulgata* (Bornemann). - NAGY and JOHANSEN, p. 25, pl. 5, figs. 17-18.

Description: Test small, elongate, cylindrical, tapered at proximal part, rapidly expanding towards distal portion; chambers three in number, increasing rapidly in diameter, last chamber inflated; sutures horizontal, flush; aperture terminal radiate; wall calcareous; surface smooth.

Dimensions (in mm): Length 0.3, width 0.16.

Remarks: A single specimen of *Pseudonodosaria vulgata* (Bornemann) was recovered from the Kachchh material which exhibits similarities to the specimens described by Nagy and Johansen (1991) from the Jurassic sediments of northern North Sea. These authors (*op. cit.*) have stated that this species shows an extremely wide range of variation. Our form is also similar in overall characters to those figured by Olszewska and Wieczorek (1988) from the Callovian-Oxfordian sediments of Poland.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 481.

Subfamily FRONDICULARIINAE Reuss, 1860

Genus FRONDICULARIA Defrance, 1826

Frondicularia kutchensis Bhalla and Abbas

Plate V, figure 5

1978 - *Frondicularia kutchensis* BHALLA and ABBAS, p. 179, pl. 7, figs. 2-3.

1991 - *Frondicularia kutchensis* Bhalla and Abbas.- BHALLA and TALIB, p. 99, pl. II, fig. 6.

Description: Test small, elongate, compressed; chambers five or more in number, chevron-shaped, increasing gradually in size as add, last chamber conspicuous by being larger than others; sutures distinct, simple depressed, arched-shaped; periphery lobulate; aperture rather indistinct, appears to be terminal radiate; wall calcareous; surface smooth.

Dimensions (in mm): Length 0.27, width 0.12, thickness 0.06.

Remarks: A solitary, poorly preserved specimen of *Frondicularia kutchensis* with broken initial portion was obtained from the present material which is similar to those described originally by Bhalla and Abbas (1978) from Jurassic rock of Habo hills, Kachchh and comes well within the variation range of this species as worked out by these authors (*op. cit.*). Bhalla and Talib (1991) also reported this species from the Jurassic sediments of Jhurio hill, Kachchh.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 482.

4.3.11 Family VAGINULINIDAE Reuss, 1860

Subfamily LENTICULININAE Chapman, Parr and Collins, 1934

Genus LENTICULINA Lamarck, 1804

Lenticulina dilectaformis Subbotina and Srivastava

Plate V, figure 6

1960 - *Lenticulina dilectaformis* SUBBOTINA and SRIVASTAVA, *in* Subbotina *et al.*, p. 15, pl. 1, figs. 2a-b.

1969 - *Lenticulina dilectaformis* Subbotina and Srivastava.- KALANTARI, p. 35. pl. 2, figs. 5a, b.

1993- *Lenticulina dilectaformis* Subbotina and Srivastava.- PANDEY and DAVE, p. 128, pl. 4, figs. 6-9; pl. 5, figs. 1-4.

Description: Test medium, sub-circular in outline, closely coiled, involute, lenticular; chambers eight to nine in number, increasing gradually in size as added, becoming very narrow near the umbilicus; sutures elevated, gently curved towards peripheral margin, fusing near umbilicus to form a broken ring; periphery subacute, keeled; apertural face triangular; aperture terminal radiate, on a small projection at peripheral angle; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.24-0.57, minor diameter 0.15-0.36, thickness 0.11-0.27.

Remarks: The present forms of *Lenticulina dilectaformis* are similar to those described originally by Subbotina and Srivastava (1960) from the Oxfordian sediments of Kachchh. Our specimens are also similar to those described by Kalantari (1969) and Pandey and Dave (1993) from Jurassic rock of N.E. Iran and Kachchh respectively. However, the forms described by Pandey and Dave (1993) have more prominent ribs and some of them show tendency to uncoil in later stage unlike ours.

L. dilectaformis differs from *L. quenstedti* in having triangular aperture face and incomplete central ring formed by fusion of sutures.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 483.

Lenticulina ectypa (Loeblich and Tappan)

Plate V, figure 7

1950b - *Astacolus ectypa* LOEBLICH and TAPPAN, p. 179, pl. 1, fig. 10.

1981 - *Lenticulina ectypa* (Loeblich and Tappan). - BARNARD, CORDEY and SHIPP, p. 412, pl. 2, fig. 19.

1981 - *Lenticulina ectypa* (Loeblich and Tappan). - SHIPP and MURRAY, p. 138, pl. 6.3.3, figs. 7-10.

2001 - *Lenticulina ectypa* (Loeblich and Tappan). - NAGY, FINSTAD, DYPVIK and BREMER, pl. 2, fig. 5.

Description: Test medium, planispiral, involute, sub-rounded to elongate, coiled to partly uncoiled; six to nine chambers, enlarging gradually in size as added; sutures distinct, deeply depressed on proximal side of each suture line, often ribbed on distal side, curved, coalesce near umbilicus to form a faint umbilical ring; periphery acute, keeled; aperture radiate, at peripheral angle; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.24-0.40, minor diameter 0.165-0.30, thickness 0.075-0.15.

Remarks: A few well preserved specimens of *Lenticulina ectypa* were recoverd from the Kachchh material. Our specimens are similar to those described by Shipp and Murray (1981) from the Callovian of Brora, England, and Barnard *et al.*, (1981) from Callovian-Oxfordian of England. The Kachchh forms also show similarities to those figured by Nagy *et al.*, (2001) from Callovian sediments of Scotland.

Our specimens of *L. ectypa* show little variation in size and shape of the test. The majority of the specimens are closely-coiled. This species resembles *L. quenstedti* but differs in having a deep recess posterior to the rib in each chamber.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 484.

Lenticulina münsteri (Roemer)

Plate V, figure 8

1839- *Robulina münsteri* ROEMER, p. 48, pl. 10, fig. 20.

1935- *Cristellaria münsteri* (Roemer).- MACFADYEN, p. 13, pl. 1, figs. 10a-b.

1958- *Lenticulina muensteri* (Roemer).- SAID and BARAKAT, p. 248, pl. 1, fig.10; pl. 3, fig. 25; pl.4, fig. 35.

1969 - *Lenticulina münsteri* (Roemer). - KALANTARI, pp. 36-37, pl. 1, figs. 1-4a, b.

1981 - *Lenticulina münsteri* (Roemer). - BARNARD, CORDEY and SHIPP, p. 413, pl. 2, figs. 20-21.

1981 - *Lenticulina muensteri* (Roemer). - BARNARD and SHIPP, p. 12, pl. 1, figs. 13-14.

1983 - *Lenticulina muensteri* (Roemer). - KALIA and CHOWDHURY, pp. 234-235, pl. 4, figs. 4-14

1991 - *Lenticulina muensteri* (Roemer). - NAGY and JOHANSEN, p. 26, pl. 5 figs. 24-25; pl. 7, figs. 8-10.

Description: Test medium to large, biconvex, planispiral, sub-rounded to elongate, closely coiled; eight to ten sub-triangular chambers, increasing gradually in size as added; sutures distinct, limbate, slightly raised, slightly curved towards the peripheral margin; periphery sub-acute with keel; apertural face triangular; aperture simple, radiate, at dorsal angle; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.27-0.93, minor diameter 0.24-0.69, thickness 0.15-0.39.

Remarks: This species of *Lenticulina* was originally described by Roemer (1839) from the Lower Cretaceous of Germany and is closely related to *L. subalata*. *L. subalata* (Reuss) has markedly raised central boss and ribs unlike the smoother *L. muensteri*. Our forms are similar to those described by Barnard *et al*., (1981) and

Barnard and Shipp (1981) from Callovian-Oxfordian of England and Boulonnais (France) respectively. Our specimens also show some similarity with those described by Said and Barakat (1958) and Kalantari (1969) from Jurassic of Egypt and Iran respectively.

Barnard and Shipp (1981) noticed that *L. münsteri* (Roemer) show slight variation in size and shape of the test and is commonly found with *L. subalata*.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 485.

Lenticulina protracta (Bornemann)

Plate V, figure 9

1854 - *Cristellaria protracta* BORNEMENN, p. 39, pl. 4, figs. 27a, b.

1935 - *Cristellaria subalata* Borneman.- MACFADYN, p. 15, pl. I, figs. 17a, b.

1969 - *Planularia protracta* (Bornemann). - KALANTARI, p. 54, pl. 3, figs. 9a-11b.

1981 - *Lenticulina protracta* (Bornemann). - BARNARD, CORDEY and SHIPP, pp. 413-414, pl. 2, fig. 22.

Description: Test small, compressed, elongate, lenticular, initially coiled, later portion uncoiled; five chambers in coiled portion, two to four in uncoiled portion, increasing gradually in size as added; sutures distinct, flushed in coiled part, slightly depressed in uncoiled portion; dorsal periphery sub-acute, slightly keeled; aperture terminal radiate, placed on a short neck; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.30-0.36, minor diameter 0.12-0.18, thickness 0.06-0.087.

Remarks: A few specimens of *Lenticulina protracta* (Bornemann) were encountered in the Kachchh material which are similar to those described by Barnard *et al.*, (1981) from the Callovian-Oxfordian clay of England and fall well within the variation range of this species. Our forms also exhibit close resemble to *Planularia protarcta* (Bornemann) described by Kalantari (1969) from Jurassic rocks of Iran.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 486.

Lenticulina quenstedti Gümbel

Plate V, figure 10

1862- *Cristellaria quenstedti* GÜMBEL, p. 226, pl. 4, figs. 2a, b.

1981- *Lenticulina quenstedti* Gümbel. - COLEMAN, p. 120, pl. 6.2.3, fig. 12.

1981- *Lenticulina quenstedti* Gümbel. - BARNARD, CORDEY and SHIPP, pp. 414- 416, pl. 2, fig. 32.

1991- *Lenticulina quenstedti* Gümbel. - BHALLA and TALIB, p. 99, pl. II, fig. 7, *et syn.*

1993- *Lenticulina quenstedti* Gümbel. - PANDEY and DAVE, pp. 129-130, pl. 6. figs. 1-9.

Description: Test medium, biconvex, planispiral, involute, closely coiled; eight to ten chambers in last whorl, well marked, increasing gradually in size as added; sutures distinct, raised, limbate, curved, coalesce near umbilicus to form circular umbilical ring; periphery acute, keeled; aperture radiate, at peripheral angle; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.36-0.60, minor diameter 0.21-0.50. thickness 0.15-0.27.

Remarks: A large population of well preserved specimens of *Lenticulina quenstedti* Gümbel was recovered from the Kachchh material. The Indian specimens are similar to those described by Kalantari (1969) from Jurassic of Iran and Barnard *et al.*, (1981) from Callovian-Oxfordian of England, showing markedly raised sutures and well developed keel. Our forms also show clear umbilical ring as figured by Bhalla and Abbas (1978), Bhalla and Talib (1985a, 1991), and Pandey and Dave (1993) from Jurassic sediments of Kachchh and Coleman (1981) from Dorset, England.

A detailed study of variation in *L. quenstedti* was carried out by Barnard *et al.* (1981) and Bhalla and Talib (1985c). Our specimens show little variation in test morphology.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 487.

Lenticulina subalata (Reuss)

Plate V, figure 11

1854 - *Cristellaria subalata* REUSS, p. 68, pl. 25, fig. 13.

1981 - *Lenticulina subalata* (Reuss). - SHIPP and MURRAY, p. 139, pl. 6.3.3, fig. 18.

1991 - *Lenticulina subalata* (Reuss). - BHALLA and TALIB, pp. 99-100, pl. II, fig. 8, *et syn.*

1993 - *Lenticulina subalata* (Reuss). - PANDEY and DAVE, pp. 198-199, pl. 6, figs. 4-6.

Description: Test small to medium, planispiral, rounded to elongate, biumbonate; ten to twelve well-marked chambers, triangular in shape, increasing gradually in size as added; sutures distinct, limbate, raised, gently curved; periphery smooth, keeled; aperture distinct, radiate, at dorsal angle; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.27-0.75, minor diameter 0.21-0.67, thickness 0.15-0.36.

Remarks: *Lenticulina subalata* (Reuss) was originally described from Cretaceous of Germany. This species shows a wide range of variation in size and shaped of the test. Bhalla and Abbas (1975b) has carried out detailed variation study of this species and observed that some of the species of *Lenticulina* erected by previous workers are in fact different morphovarient of *L. subalata*, and were shown to intergrade to one another. Our specimens of *L. subalata* are similar to those described by Bhalla and Abbas (1978), Bhalla and Talib (1991), and Pandey and Dave (1993) from the Jurassic sediments of Kachchh and show similar trend of variation. The present specimens are also identical to those described by Said and Barakat (1958) and Kalantari (1969) from the Jurassic rocks of Egypt and Iran respectively. Kalantari (1969) differentiated this species from *L. münsteri* (Roemer) in having a raised, broader and stronger keel. Barnard *et al.* (1981) noted that *L. subalata* can be distinguished from *L. münsteri* by the presence of sharp keel, strongly raised suture ribs and raised central boss.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 488.

Lenticulina tricarinella (Reuss)

Plate V, figure 12

1863 - *Cristellaria* (*tricarinella*) *tricarinella* REUSS, p. 68, pl. 7, fig. 9; pl. 12, figs. 2-4.

1981 - *Lenticulina tricarinella* (Reuss). - COLEMAN, p.120, pl. 6.2.3, figs. 14-15.

1991 - *Lenticulina tricarinella* (Reuss). - BHALLA and TALIB, p. 100, pl. II, fig. 12, *et syn.*

1993 - *Lenticulina tricarinella* (Reuss). - PANDEY and DAVE, p. 132, pl. 7, figs. 7-8; pl. 8, figs. 1-5.

Description: Test small to medium, compressed, parallel sided in front view; early part planispiral, with three to four chambers; later portion tending to uncoil with two to four chambers, forming a rectilinear series; chambers broad, low, increasing rapidly in size with growth, tending to reach proloculus; sutures distinct, raised, limbate, curved towards outer margin, oblique to axis of coiling; periphery entire, tricarinate, keeled; aperture distinct, radiate, on a short neck at dorsal angle; wall calcareous; surface smooth.

Dimension (in mm): Major diameter 0.045-0.60, minor diameter 0.225-0.33, thickness 0.09-0.12.

Remarks: A few well preserved specimens of *Lenticulina tricarinella* (Reuss) were recovered from the present material. This species is a famous and well established Jurassic species of *Lenticulina*, first described by Reuss (1863) from the Lower Cretaceous of North Germany. Our forms are similar to those described by Said and Barakat (1958), Kalantari (1969), Bhalla and Abbas (1978), Coleman (1981), and Pandey and Dave (1993).

Lenticulina tricarinella (Reuss) shows wide variation in size and shape of the test as well as number of chambers comprising the coiled and uncoiled portion. A detailed variation of this species has been worked out by Bhalla and Abbas (1978).
Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 489.

Subfamily PALMULINAE Saidova, 1981

Genus NEOFLABELLINA Bartenstein, 1948

Neoflabellina ovalis (Wedekind)

Plate V, figure 13

1840 - *Flabellina ovalis* WEDEKIND, p. 187, text-fig. 5a-c.

1969 - *Neoflabellina ovalis* (Wedekind). - KALANTARI, p. 193, pl. 26, fig. 7.

Description: Test small, palmate, oval, flattened; early portion *Citharine*, proloculus followed by three to four triangular chambers, increasing gradually as added; later portion *Frondicularine*, with two to five chevron shaped chambers increasing gradually in width and height as added; sutures distinct, limbate, slightly raised, gently curved in *Citharine* portion, acutely arched in later part; aperture terminal radiate; wall calcareous; surface coarsely perforate.

Dimensions (in mm): Length 0.25-0.36, width 0.12-0.21, thickness 0.04-0.06.

Remarks: Specimens of *Neoflabellina ovalis* (Wedekind) are abundantly found in the present material which are similar to those reported by Kalantari (1969) from the Upper Cretaceous of Iran, but differ in being smaller in size and having lesser number of chambers in the *Frondicularine* portion. In some specimens, elevated sutures tend to break up into nodes.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No MF. 490.

Subfamily MARGINULININAE Wedekind, 1937

Genus ASTACOLUS de Montfort, 1808

Astacolus anceps (Terquem)

Plate V, figure 14

1870 - *Cristellaria anceps* TERQUEM, p. 428, pl. 9, figs. 11-21.

1978 - *Astacolus anceps* (Terquem). - BHALLA and ABBAS, p. 175, pl. 5, fig. 1.

1991 - *Astacolus anceps* (Terquem). - BHALLA and TALIB, p. 97, pl. I, fig. 9.

Description: Test small, elongate, compressed; chambers distinct, six in number, increasing gradually as added, final chamber occupy major portion of entire length; sutures distinct, initially flush, later slightly depressed, curved; periphery carinate; aperture distinct, terminal radiate; wall calcareous; surface smooth.

Dimensions (in mm): Maximum length 0.27, maximum width 0.13, thickness 0.04.

Remarks: A solitary specimen of *Astacolus anceps* (Terquem) was recovered from the present material. Our form is similar to those described by Subbotina and Srivastava (*in* Subbotina *et al.*, 1960), Bhalla and Abbas (1978), and Bhalla and Talib (1991) from the Jurassic deposits of Kachchh but differs in having slightly depressed sutures in later stage like the Iranian form (Kalantari, 1969).

Occurrence: Rare.

Repository of type materia: AMUGD Cat. No. MF. 491.

Astacolus sp. indet.

Plate V, figure 15

Description: Test medium, compressed, elongate, early portion coiled, later portion uncoiled; coiled portion with five chambers, enlarging gradually as added; uncoiled portion with three chambers, tending to reach proloculus, increasing gradually in size as added, broader than high; sutures distinct, nearly flush in early portion, depressed in later part, oblique to axis of coiling, sutures with thin broken ribs, giving a beaded appearance; periphery slightly lobulate; aperture indistinct, appears to be radiate, at dorsal angle; wall calcareous; surface smooth.

Dimensions (in mm): Length 0.63, width 0.33, thickness 0.09.

Remarks: A single specimen of *Astacolus* was recovered from the present material, which could not be assigned to any known species of the genus. However, it shows some resemblance to *Astacolus filosa* (Terquem), described by Said and Barakat (1958) from Jurassic rocks of Egypt but differs in having flush sutures in the early portion and smaller number of chambers in the coiled portion. The beaded ribs along the sutures is the characteristic feature of this species unlike *A. filosa* (Terquem) figured by Said and Barakat (*op. cit.*). However, a single specimen does not allow assigning a trivial name.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 492.

Genus HEMIROBULINA Stache, 1864

Hemirobulina sastyri (Bhalla and Talib)
Plate V, figure 16

1985 - *Marginulina sastryi* BHALLA and TALIB, pp. 149-150, pl. 1, figs.1-9.
1991 - *Marginulina sastryi* Bhalla and Talib. - BHALLA and TALIB, p. 101, pl. III, figs. 3-5.

Description: Test small, elongate, gently arcuate, inflated, early portion loosely coiled, later part uncoiled; chambers five in number, enlarging gradually as added, early chambers triangular, later ones rectilinear; sutures simple, depressed, slightly curved in early portion, later oblique to axis; aperture terminal radiate; wall calcareous; surface smooth.

Dimensions (in mm): Maximum length 0.23, maximum width 0.09, thickness 0.07.

Remarks: A single specimen of *Hemirobulina* was obtained from the present material which is more or less similar to *Hemirobulina sastryi* (=*Marginulina sastryi*) described by Bhalla and Talib (1985b, 1991), from the Jurassic sediments of Kachchh but differs in having a slightly longer neck.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 493.

Genus MARGINULINA d' Orbigny, 1826

Marginulina caelata Loeblich and Tappan

Plate VI, figure 1

1950a - *Marginulina caelata* LOEBLICH and TAPPAN, p. 46, pl. 12, figs. 10a, b.
1963 - *Marginulina caelata* Loeblich and Tappan. - ESPITALIE and SIGAL, pp. 42-43, pl. XVIII, figs. 8-11.

Description: Test small, elongate, compressed, early portion arcuate, later uncoiled, rounded in section; chambers five in number, increasing gradually in size as added; sutures distinct, depressed, initially slightly curved, later oblique to test axis; aperture terminal radiate, at the end of a short neck; wall calcareous; surface ornamented with very fine longitudinal costae, about twenty-three in number.

Dimensions (in mm): Maximum length 0.21, maximum width 0.09, thickness 0.07.

Remarks: A solitary specimen of *Marginulina caelata* was found in our material which is similar in all characters to those described originally by Loeblich and Tappan (1950a) from the Oxfordian of North America. However, the Kachchh form has a smaller apertural neck than the American forms.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 494.

Marginulina oxfordiana Gordon

Plate VI, figure 2

1965- *Marginulina oxfordiana* GORDON, p. 842, text-fig. 6, figs. 28-31.

1991- *Marginulina oxfordiana* Gordon.- BHALLA and TALIB, p. 101, pl. III, figs. 16-17.

Description: Test small, elongate, slightly compressed, arcuate, initially slightly coiled, later uncoiled, sub-parallel, uniserial; chambers five in number, enlarging gradually in size as added, later chambers slightly inflated; sutures distinct, depressed, oblique; aperture terminal radiate; wall calcareous; surface ornamented by numerous, longitudinal costae.

Dimensions (in mm): Maximum length 0.27-0.36, maximum width 0.075-0.12, thickness 0.06-0.77.

Remarks: Specimens of *Marginulina oxfordiana* were abundantly recovered from the present material which resemble those described originally by Gordon (1965) from Jurassic of England but differ in having smaller number of chambers. Our forms are similar to those described by Bhalla and Talib (1991) from the Jurassic sediments of Kachchh.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 495.

Marginulina aff. *M. sculptilis* (Schwager)
Plate VI, figure 3

1865 - aff. *Cristellaria sculptilis* SCHWAGER, p. 129, pl. 6, fig.10.
1965 - aff. *Marginulina sculptilis* (Schwager). - GORDON, pp. 842-843, text-fig. 6, figs. 23-25.

Description: Test small, slightly compressed, initial portion tending to coil; chambers six in number, rectilinear, increasing gradually in size, final chamber smaller than the previous one, nearly triangular; sutures distinct, depressed, oblique to test axis; periphery arcuate; aperture terminal radiate, place at the end of a short neck; wall calcareous; surface ornamented by numerous, longitudinal costae.

Dimensions (in mm): Maximum length 0.27-0.33, maximum width 0.08, thickness 0.10.

Remarks: A few specimens of *Marginulina* were recovered from the Kachchh material having affinity with *Marginulina sculptilis* (Schwager) described by Gordon (1965) from the Oxfordian rocks of England. Our Forms differ from the English forms in having larger number and finer longitudinal costae and chambers tending to reach proloculus. However, as mentioned by Gordon (1965), ornamentation is highly variable in these forms.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No MF. 496.

Genus VAGINULINOPSIS Silvestri, 1904

Vaginulinopsis aff. *V. misrensis* Said and Barakat

Plate VI, figure 4

1958 - *Vaginulinopsis misrensis* SAID and BARAKAT, pp. 251-252, pl. 5, figs. 7a-c, 21a, b

1969 - *Vaginulinopsis misrensis* Said and Barakat. - KALANTARI, pp. 88-89, pl. 6, figs. 1-6.

Description: Test small, elongate, slightly compressed, dorsal margin distinctly keeled, initial portion closely coiled, later uncoiled, uniserial; coiled portion with four chambers, uncoiled portion with three rectilinear chambers; penultimate chamber slightly globular, larger than final chamber; sutures depressed, slightly thickened, gently curved in coiled portion, oblique in later part; aperture terminal radiate; wall calcareous; surface smooth.

Dimensions (in mm): Maximum length 0.27, maximum width 0.10, thickness 0.06.

Remarks: A single specimen of *Vaginulinopsis misrensis* was found in Kachchh material which is similar to those described originally by Said and Barakat (1958) from Jurassic rocks of Egypt. Our form is similar to the Egyptian specimens in all characters but differs in having a faint keel, lesser number of chambers in the uncoiled portion and thick sutures. This species is also reported by Kalantari (1969) from Jurassic rocks of Iran showing similarities to the original one.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 497.

Subfamily VAGINULININAE Reuss, 1860

Genus CITHARINA d' Orbigny, 1839

Citharina clathrata (Terquem)

Plate VI, figure 5

1864 - *Marginulina longuemari* var. *clathrata* TERQUEM, p. 402, pl. 8, figs. 16, 19a, b.

1969 - *Citharina clathrata* (Terquem). - KALANTARI, pp. 58-60, pl. 5, figs. 25-26.

1978 - *Citharina clathrata* (Terquem). - BHALLA and ABBAS, pp. 176-177, pl. 5, fig. 8; pl. 9, figs. 1-5. *et syn.*

1991- *Cithrina clathrata* (Terquem). - BHALLA and TALIB, p. 97, pl. II, fig. 2.

Description: Test small to large, elongate, compressed to slightly inflated, flaring, triangular in outline, maximum width nearly at the middle of the test; chambers six to nine in number, broader than high, increasing rapidly in breadth but gradually in height as added; sutures distinct, thickened, initially flush with surface, later slightly depressed, gently curved, oblique to test axis, sub-parallel to one another; periphery entire, keeled; apertural margin straight to gently curved; peripheral margin convex; aperture radiate, at dorsal angle; wall calcareous; surface ornamented with eight to eleven longitudinal costae, uninterrupted by sutures, sometimes bifurcating.

Dimensions (in mm): Maximum length 0.30-0.75, maximum width 0.13-0.45, thickness 0.08-0.18.

Remarks: A fairly rich population of *Cithrina clathrata* was found in our material. Present specimens are similar to those described by various workers from Jurassic sediments, *viz.*, Kalantari (1969) from Iran, Bhalla and Abbas (1978) from Habo hills, Kachchh, and Bhalla and Talib (1991) from Jhurio hills, Kachchh, but differ in having a slightly larger number of ornamented ribs. Bhalla and Abbas (1978) worked out variation and dimorphism in this species. These authors noted that *C. pseudolatissima* reported by Subbotina and Datta (*in* Subbotina *et al.*, 1960) from the Jurassic of Kachchh is similar to *C. clathrata* in all respects and that the former should be treated as a junior synonym of *C. clathrata*. *C. clathrata* recovered from the present material show a wide range of variation in shape, size and compression of the test as well as number of chambers and ornamental ribs.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 498.

Suborder ROBERTININA Loeblich and Tappan, 1984

Superfamily CERATOBULIMINACEA Cushman, 1927

4.3.12 Family EPISTOMINIDAE Wedekind, 1937

SubFamily EPISTOMININAE Wedekind, 1937

Genus EPISTOMINA Terquem, 1883

Epistomina minutereticulata Espitalie and Sigal

Plate VI, figures 6-7

1963 - *Epistomina minutereticulata* ESPITALIE and SIGAL, p. 66, Pl. XXXI, figs. 3-4.

1977 - *Epistomina minutereticulata* Espitalie and Sigal. - SINGH, p.31, pl. 1, figs. 7-11.

1979 - *Epistomina minutereticulata* Espitalie and Sigal. - SINGH, pl. 8, fig. 11.

1993 - *Epistomina minutereticulata* Espitalie and Sigal. - PANDEY and DAVE, pp. 142-143, pl. 20, figs. 8-9; pl. 21, fig. 1.

Description: Test small to medium, trochospiral, nearly circular in outline, biconvex, ventrally more convex; two whorls visible on dorsal side, with seven chambers in the last whorl; chambers V-shaped, increasing gradually in size as added, initial whorl coarsely reticulated, ventral chambers triangular; umbonal mass on ventral side strongly elevated, coarsely pitted; dorsal sutures, thick, raised, fairly curved; ventral sutures radial, thicker than dorsal ones; periphery sub-acute, keeled, secondary keel discontinuous, weak; aperture indistinct, secondary aperture as peripheral slits between the keels; wall calcareous; surface rough.

Dimension (in mm): Major diameter 0.31-0.43,. minor diameter 0.28-0.40, thickness 0.18-0.25.

Remarks: Specimens of *Epistomina minutereticulata* are abundantly found in our material and are similar to those described originally by Espitalie and Sigal (1963) from the Jurassic sediments of Madagascar. Our forms are also similar to those described by Pandey and Dave (1993). Fine reticulation on both sides is the main distinguishing feature of the species.

Occurrence: Abundant.

Repository of type material: AMUGD Cat. No. MF. 499.

Epistomina parastelligera (Hofker)

Plate VI, figures 8-9

1954 - *Brotzenia parastelligera* HOFKER, p. 88, text-fig. 4-6.

1958 - *Epistomina parastelligera* (Hofker). - SAID and BARAKAT, p. 267, pl. 3, fig. 43; pl. 5, figs. 35a-c.

1967 - *Epistomina parastelligera* (Hofker). - GORDON, p. 458, pl. 4, fig 32.

1969 - *Brotzenia parastelligera* Hofker.- KALANTARI, pp. 105-106, pl. 10, figs. 7a-c.

1981 - *Brotzenia parastelligera* Hofker. - BARNARD, CORDEY and SHIPP, p. 432, pl. 4, figs. 14-17.

1988- *Epistomina parastelligera* (Hofker). - OLSZEWSKA and WIECZOREK, pl. I, fig. 29.

2001- *Epistomina parastelligera* (Hofker). - NAGY, FINSTAD, DYPVIK and BERMER, pl. 2, figs. 17-18.

Description: Test small, trochospiral, sub-circular in outline, biconvex; dorsal side with eight indistinct, trapezoid chambers in final whorl; dorsal sutures indistinct, slightly thick, raised; ventral sutures, indistinct, nearly radial, broadly raised; periphery keeled; aperture indistinct, appears to be at the base of final chamber; secondary aperture rather indistinct, slit-like along the peripheral margin; wall calcareous; surface somewhat rough.

Dimensions (in mm): Major diameter 0.24, minor diameter 0.19, thickness 0.09.

Remarks: A solitary specimen of *Epistomina parastelligera* (Hofker) was found in the present material which resembles those described by Said and Barakat (1958) and Kalantari (1969) from the Callovian sediments of Egypt and NE Iran respectively. The Indian form is closer to Egyptian forms and those figured by Nagy *et al.*, (2001) from Callovian sediments of northeastern Scotland. Olszewska and Wieczorek (1998) also reported this species from the Callovian-Oxfordian sediments of southern Poland, exhibiting fairly raised sutures on the dorsal side, unlike our form.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 500.

Epistomina regularis Terquem

Plate VI, figures 10-11

1883 - *Epistomina regularis* TERQUEM, p. 379, pl. 44, figs. 1a-c, 2-3.

1978 - *Epistomina regularis* Terquem. - GRADSTEIN, pl.2; figs. 2a, b; 4a, b.

1981- *Epistomina regularis* Terquem. - COLEMAN, pp. 116-118, pl. 6.2.2, figs. 11-12.

1988- *Epistomina regularis* Terquem. - GOVINDAN, CHIDAMBRAM and BHANDARI, pp. 71-72, pl.1, fig. 9.

1988- *Epistomina regularis* Terquem. - WILLIAMSON and STAM, p. 44, pl. 4, figs. 7-9.

Description: Test medium, trochospiral, sub-circular in outline, biconvex; two whorls visible on dorsal side, with seven to eight trapezoid chambers in final whorl, increasing gradually in size as added, chambers reticulated on initial whorl; dorsal sutures slightly thick, elevated; ventral sutures radial, thick, elevated; ventral side pitted; periphery sub-acute, keeled; aperture aerial, oval, on the umblical side; secondary apertures slit-like, along the peripheral margin; wall calcareous; surface somewhat rough.

Dimensions (in mm): Major diameter 0.30-0.48, minor diameter 0.25-0.42, thickness 0.14-0.18.

Remarks: A few specimens of *Epistomina regularis* Terquem were obtained from the present material which are similar in overall characters to those described by Coleman (1981) from the Jurassic rocks of Dorset and Williamson and Stam (1988) from the Jurassic of Canada and Europe but differ in having slightly thicker and raised sutures on the ventral side.

Williamson and Stam (1988) mentioned that the main character of this species is pitting or an irregular pattern of ridges on umbilical side which distinguishes it form the smoother *E. mosquensis* which also possesses a sharp collar in the centre of the ventral side.

Occurrence: Frequent to rare.

Repository of type material: AMUGD Cat. No. MF. 501.

Epistomina tenuicostata Bartenstein and Brand

Plate VI, figures 12-13

1951 - *Epistomina tenuicostata* BARTENSTEIN and BRAND, p. 327, pl. 12A, figs. 325a-c.

1969 - *Brotzenia tenuicostata* (Bartensten and Brand). - KALANTARI, pp. 169-170, pl. 15, figs.1-4a-c.

1965 - *Brotzenia tenuicostata* (Bartensten and Brand). - GORDON, p. 859, text-fig. 10, figs. 10-14.

1981 - *Epistomina tenuicostata* Bartensten and Brand. - SHIPP and MURRAY, p. 136, pl. 6.3.2., figs. 20-22.

1987 - *Epistomina tenuicostata* Bartensten and Brand. - WILLIAMSON, p. 54, pl. 3, figs. 16-18.

1988 - *Epistomina tenuicostata* Bartensten and Barnard. - WILLIAMSON and STAM, p. 146, pl. 4, figs.3, 6.

Description: Test small, trochospiral, biconvex, nearly circular in outline, gently convex on dorsal side, ventrally more convex; two whorls visible on dorsal side, with seven trapezoid chambers in final whorl, increasing gradually as added, last chamber overlapping the umbilicus on spiral side; sutures on spiral side distinct, slightly irregular, limbate, elevated, strongly curved, making reticulate pattern on initial whorl; ventral sutures radial, limbate, slightly raised to flush, gently curved towards the periphery; periphery acute, keeled; aperture oblique, areal, oval, on the umbilical side, secondary apertures indistinct; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.29-0.33, minor diameter 0.28-0.31, thickness 0.22-0.27.

Remarks: A few specimens of *Epistomina tenuicostata* Bartensten and Brand, were found in our material which show similarities in all characters to those described by Shipp and Murray (1981) from Oxfordian of England and

Williamson and Stam (1988) from Jurassic sediments of Canada and Europe. The main characteristic feature of this species is the nature of last chamber on the ventral side which overlaps a part of the umbilical area.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 502.

Epistomina sp. indet.

Plate VI, figures 14-15

Description: Test small, trochospiral, biconvex, almost circular in outline, three whorls visible, with seven chambers in the final whorl; chambers of dorsal side trapezoid, increasing gradually in size as added; chambers of ventral side, triangular; dorsal sutures distinct, limbate, slightly raised, curved, making small reticulation on initial whorl; ventral sutures limbate, straight, very slightly raised, converging at centre, pitted near umbilical area; periphery acute, distinctly keeled; aperture areal, oblique, oval, secondary apertures slit like, lying between the keel; wall calcareous; surface smooth.

Dimensions (in mm): Major diameter 0.38, minor diameter 0.37, thickness 0.20.

Remarks: A solitary specimens of *Epistomina* was obtained from the Kachchh material which could not be compared with any described species of the genus.

Occurrence: Rare.

Repository of type material: AMUGD Cat. No. MF. 503.

Figure 4

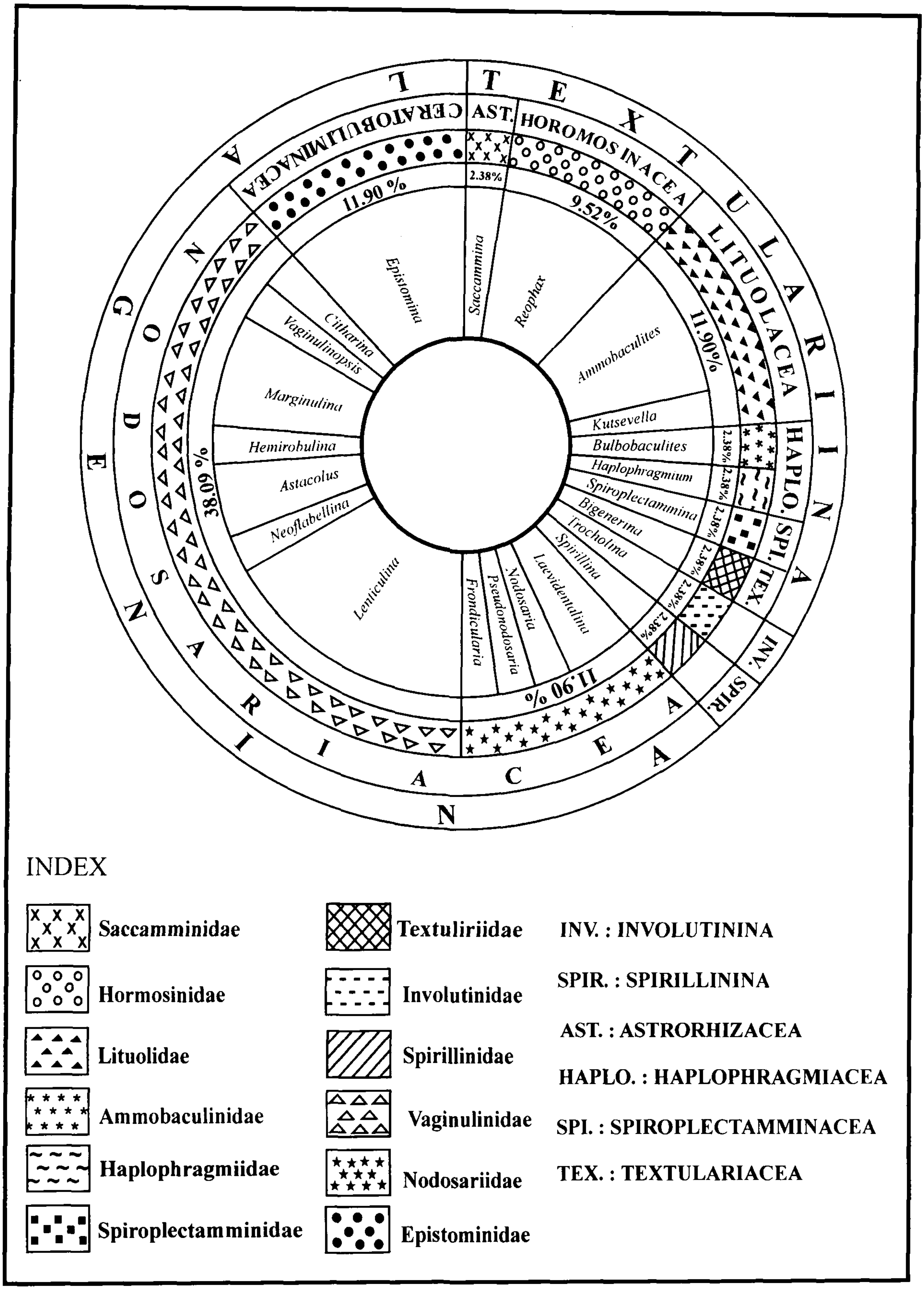


Figure 4. Composition of foraminiferal assemblage, Ler hill, Kachchh

CHAPTER 5

FORAMINIFERAL COMPOSITION AND BIOSTRATIGRAPHY

5.1 COMPOSITION OF THE FORAMINIFERAL ASSEMBLAGE

The Jurassic sediments belonging to Chari Formation exposed at Ler hill, Kachchh yielded a total of forty-two benthic foraminiferal species from thirty-three samples. Of these, fifteen are being described for the first time from the Indian region, *viz.*, *Saccammina* cf. *S. franconica*, *Reophax metensis*, *Reophax* aff. *R. scorpiurus*, *Kutsevella spilota*, *Bulbobaculites vermiculus*, *Laevidentalina* aff. *D. oppeli*, *Pseudonodosaria vulgata*, *Lenticulina ectypa*, *Lenticulina protracta*, *Neoflabellina ovalis*, *Marginulina caelata*, *Marginulina* aff. *M. sculptilis*, *Vaginulinopsis misrensis, Epistomina parastelligera*, and *E. tenuicostata*.

Four species of the present foraminiferal assemblage do not resemble any known described species. These are *Spiroplectammina* sp., *Bigenerina* sp., *Astacolus* sp., and *Epistomina* sp. These are probably new species but more specimens are required to assign specific names.

The Ler foraminiferal assemblage includes four suborders, *viz.*, Lagenina, having twenty-six species (61.90%), Textulariina represented by fourteen species (33.33%), and Involutilina and Spirillina having one species each representing 2.38% (figure 4).

The foraminiferal assemblage from the Ler hill is dominated by the family Vaginulinidae which comprises sixteen species belonging to seven genera, covering 38.09% of the total population. Other families are Lituolidae having five species belonging to two genera (11.90%), Nodosariidae including five species belonging to four genera (11.90%), Epistominidae having five species belonging to one genus (11.90%), Hormosinidae comprising four species of one genus (9.52%). Families Saccamminidae, Ammobaculinidae, Haplophragmiidae,

Figure 5

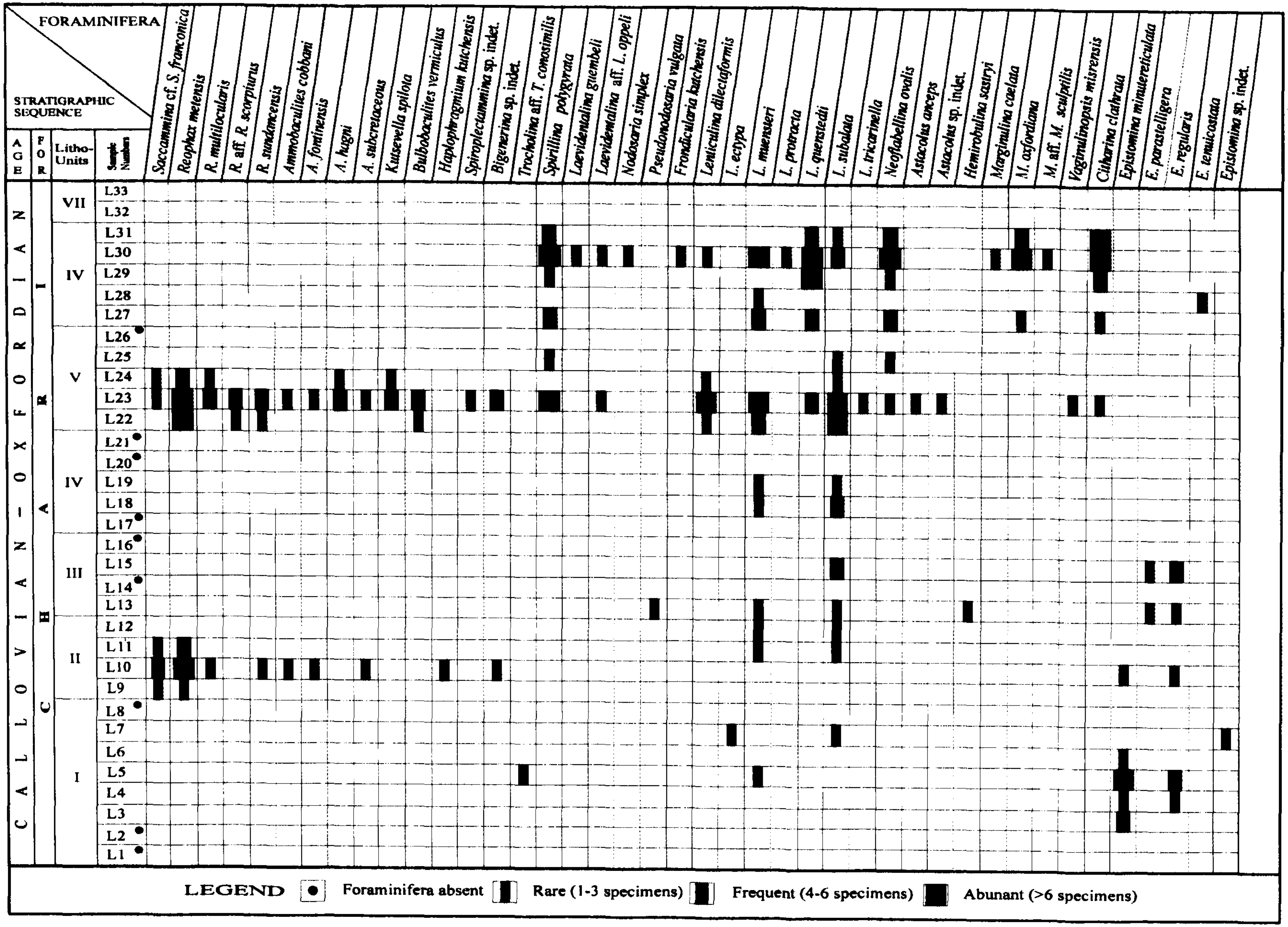


Figure 5. Frequency distribution of foraminifera in the Jurassic sequence at Ler, Kachchh

Spiroplectamminidae, Textulariidae, Involutinidae and Spirillinidae each having one species belonging to one genus and constitute 2.38% each of the total foraminiferalapecies. The frequency distribution of the foraminiferal species is shown in figure 5.

Apart from the Jurassic foraminiferal species, few post-Jurassic species belonging to *Ammonia*, *Elphidium*, and *Cibicides* were also encountered in the present assemblage. Such anomalous occurrences have also been reported by various earlier researchers working on Kachchh Jurassic.

Agrawal and Singh (1961) reported Tertiary genus *Elphidium* in the Jurassic foraminiferal assemblage of Kachchh but these authors did not mention the cause of this anomaly.

Bhalla and Abbas (1975a) reported thirteen post-Jurassic foraminiferal genera from the Jurassic assemblage of Habo hill, Central Kachchh. On the basis of obliterated morphological features, frosted surface and well rounded shape, these authors (*op. cit.*) suggested that the post-Jurassic foraminifera are not indigenous but were brought in from the neighboring exposures by natural agents like storm wind.

Shringarpure *et al.* (1976) reported foraminifera, ostracodes, bryozoans, and echinoderm spines together with microscopic plant tissues and insect skeletons of Tertiary, sub-Recent and Recent age from older Mesozoic rocks and suggested that natural agencies like storm wave, stream current, wind action, ice rafting and birds were responsible for this unusual mixing.

Bhalla and Talib (1985c) and Talib and Bhalla (2006a) mentioned the occurrence of a few post-Jurassic species in the Jurassic foraminiferal assemblage of Jhurio hill, Kachchh belonging to genera *Spiroloculina*, *Quinqueloculina*, *Triloculina*, *Uvigerina*, *Ammonia*, *Elphidium*, *Globigerina*, *Amphistegina*, and *Cibicides*. They attributed this occurrence to strong westerly winds prevailing in this region during summer which brought these elements from Tertiary sediments and Recent beaches exposed nearby in the west, as the specimens show the signs of wind-borne sediments. Thereafter, these post- Jurassic elements were entombed in the Jurassic sediments by the percolating waters during monsoon season.

Gaur and Singh (2000) reported some post-Jurassic elements mixed with Jurassic foraminifera in the Chari and Katrol formations of Nara Dome, Kachchh comprising *Quinqueloculina* sp., *Triloculina* sp., *Ammonia* sp., *Elphidium* sp. and *Cibicides* sp. but these authors (*op. cit.*) did not explain the cause of this mixing.

Gaur and Sisodia (2000) mentioned the occurrence of some post- Jurassic genera, *viz.*, *Ammonia, Spiroloculina, Elphidium, Nonion, etc.* in the Jurassic foraminiferal assemblage of Keera hills without explaining the cause of this unusual occurrence.

5.2 FORAMINIFERAL BIOCHRONOLOGY

Foraminifera have proved their excellence for dating Lower Jurassic rocks, the time resolution sometimes matching with that of ammonites (Herrero *et al.*, 1996). However, they are not very reliable for precise dating of Middle and Upper Jurassic sediments in the Indian region. Majority of Middle and Upper Jurassic foraminifera are long ranging and marker benthonic species as well as planktonic forms are either rare or absent (Bielecka and Pozaryski, 1954; Gordon, 1965; Bhalla and Abbas, 1976; Coleman *et al.*, 1981; Kalia and Chowdhury, 1983; Bhalla and Talib, 1985c, 1991). Some of the species have extremely long ranges and extend even up to Cretaceous, e.g., *Ammobaculites coprolithifomis*. *Lenticulina subalata,* and *L. tricarinella* and a few even up to Recent, *viz.*. *Ammobaculites reophaciformis and Laevidentalina gümbeli.* In addition to this. Jurassic foraminiferal assemblages are nearly always dominated by vaginulinids and nodosariids which show extreme morphological variation during this period. thus making their identification difficult, sometimes even up to generic level. This resulted in long synonymies which created much confusion in the systematics of

Middle and Upper Jurassic foraminifera. Some of the commonly occurring but long-ranging species, *viz.*, *Lenticulina subalata* and *L. tricarinella* exhibit extreme degree of variation in their morphology and could be of some stratigraphic value only when their temporal variation is thoroughly investigated.

Gradstein (1978) and later Pandey and Dave (1993), however, recommended the use of species of *Garantella, Reinholdella*, and reticulate *Epistomina* in Jurassic biostratigraphy. Williamson and Stam (1988) also opined that species of *Epistomina* are useful biostratigraphic markers during Jurassic, at least up to stage level.

The Jurassic rocks of Kachchh contain a rich foraminiferal assemblage which is rather endemic in nature (Bhalla and Abbas, 1976b; Bhalla and Talib 1991: Pandey and Dave, 1993) and the present foraminiferal assemblage also exhibits this character. Majority of the Jurassic foraminiferal species in the present assemblage are long ranging which are not truly ideal forms for dating and planktonic forms are absent. Therefore, precise dating of these deposits employing foraminiferal evidence alone is difficult and much work is needed before Middle and Upper Jurassic foraminifera from Kachchh can be relied upon as precise age markers. For best results, the approach should be towards combined study with ammonites, which have been commonly used as markers for delineating different zones of Jurassic successions in various parts of the world and calibrating them with the standard Jurassic ammonite zones of Europe.

From the above discussion it is apparent that Middle and Upper Jurassic foraminifera are not very reliable for accurate age determination. However, the presence of a few species with fairly restricted geological range helped in assigning a reasonably accurate age to the present sequence.

Figure 6

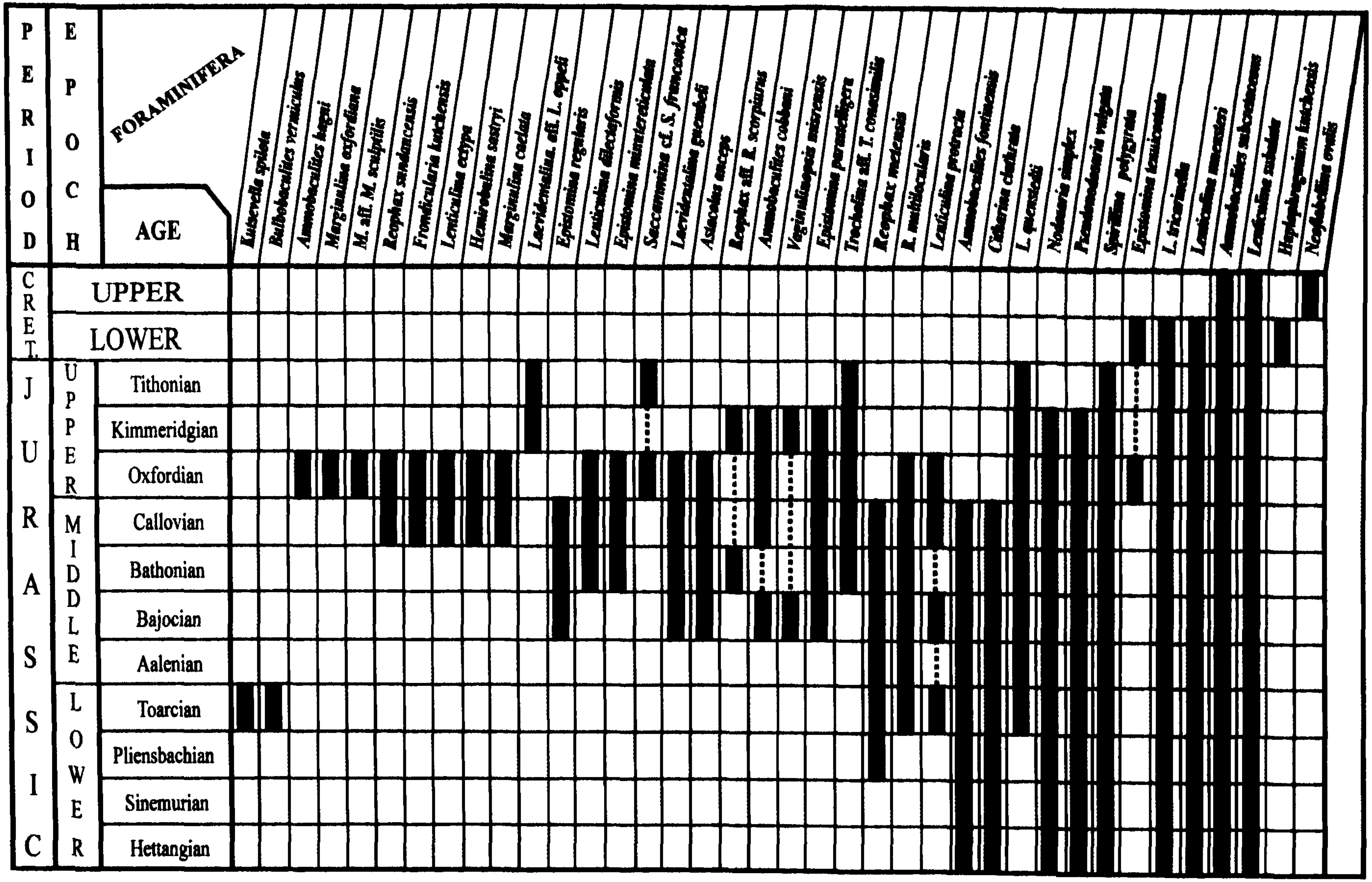


Figure 6. Known ranges of foraminifera from Ler hill, Kachchh

The Jurassic foraminiferal fauna from Ler Hill contains a number of well-known species which have been reported from Middle and Upper Jurassic sediments of various parts of the world (figure 6).

Kutsevella spilota and *Bulbobaculites vermiculus* first described from Toarcian deposits of Anholt, Denmark (Nagy and Seidenkrantz, 2003) have also been recorded from the present assemblage.

Few species which are restricted within the Oxfordian sediments have also been recovered from the present section, *viz.*, *Ammobaculites hagni*, *Marginulina oxfordiana,* and *Marginulina* cf. *M. sculptilis. Ammobaculites hagni* was originally described from Callovian-Oxfordian sediments of Kachchh (Bhalla and Abbas, 1978) but presumably this species is an Oxfordian representative as it is restricted only in the last sampling unit of Habo hills sequence (Bhalla and Abbas, 1978). *Marginulina oxfordiana* originally described by Gordon (1965) is a typical Oxfordian form, reported from the Oxfordian deposits of England and Kachchh by Gordon (1965) and Bhalla and Talib (1991) respectively. *Marginulina* cf. *M. sculptilis* is recorded from the Oxfordian deposits of Bavaria (Germany) by Schwager (*fide* Gordon, 1965), Switzerland (Haeusler, 1890), and Dorset, England (Gordon, 1965).

In the present assemblage, a significant number of foraminiferal species have restricted vertical range extending from Callovian to Oxfordian, *viz.*, *Reophax sundancensis*, *Frondicularia kutchensis*, *Lenticulina ectypa*, *Hemirobulina sastryi*, and *Marginulina caelata. Reophax sundancensis* was originally described from Oxfordian of South Dakota by Loeblich and Tappan (1950a). This species is also reported from Callovian-Oxfordian sediments of Kachchh (Gaur and Singh, 2000). *Frondicularia kutchensis* ranges from Callovian to Oxfordian of Kachchh (Bhalla and Abbas, 1978; Bhalla and Talib, 1991). *Lenticulina ectypa* ranges from Callovian to Oxfordian. Loeblich and Tappan (1950b) reported this species from Callovian of England. Nagy *et al.*, (2001) reported it from Callovian of Scotland while Barnard *et al.*, (1981) recovered this species from Callovian-Oxfordian deposits of England. *Hemirobulina sastryi* (= *Marginulina sastryi*) was originally described by Bhalla and Talib (1985b, 1991) from Callovian-Oxfordian sediments of Kachchh. *Marginulina caelata*, originally recorded from the Oxfordian rocks of North America (Loeblich and Tappan, 1950a), also occurs in Callovian to Oxfordian deposits of Madagascar (Espitalie and Sigal, 1963).

Another species with a relatively short vertical range which is present in the present assemblage is *Laevidentalina* aff. *L. oppeli* (=*Denatlina oppeli*) which ranges from ?Kimmeridgian to Portlandian of Madagascar (Espitalie and Sigal, 1963).

A few foraminiferal species from the present assemblage have slightly longer vertical ranges within Middle to Upper Jurassic. *Epistomina regularis* ranges from Bajocian to Callovian. Grandstein (1978) recorded it from Bathonian to Callovian deposits of Grand Banks, Newfoundland and Coleman *et al.* (1981) reported this species from Bajocian to Bathonian of Britain. This species is also reported from Bathonian to Callovian of Canadian Atlantic Shelf (Ascoli, 1988). Govindan *et al.* (1988) reported it from Bathonian sediments of Kachchh. Williamson and Stam (1988) described this species from Lower Middle Jurassic only while Grigelis and Ascoli (1995) reported it from Late Bajocian to Callovian of Canadian Atlantic Shelf and Late Bajocian to Middle Callovian of East European Platform. *Lenticulina dilectaformis* and *Epistomina minutereticulata* range from Bathonian to Oxfordian. *Lenticulina dilectaformis* was originally described from Oxfordian deposits of Kachchh and Jaisalmer (Subbotina *et al.*, 1960). It is also reported from Bathonian to Callovian section of Kachchh (Singh, 1977; Pandey and Dave, 1993). *Epistomina minutereticulata* ranges from Bathonian to Callovian of Madagascar (Espitalie and Sigal, 1963) and Callovian to Oxfordian of Kachchh (Singh, 1977, 1979; Pandey and Dave, 1993). This species is also recorded from the Callovian deposits of Canadian Atlantic Shelf (Ascoli, 1988). Hence, the total range of this species is Bathonian to Oxfordian. *Saccammina* cf. *S. franconia* ranges from Oxfordian to Tithonian sediments of Canada (Souyaya, 1976).

Laevidentalina gümbeli (= *Dentalina gümbeli*) ranges from Bajocian to Oxfordian (Gordon 1965, 1966, 1967; Bhalla and Abbas, 1978; Bhalla and Talib, 1991; Coleman *et al.*, 1981; Basha, 1983; Medd, 1983; Kalia and Chowdhury, 1983). However, this species abundantly occurs in Callovian-Oxfordian strata (Talib and Bhalla, 2006). *Astacolus anceps* ranges from Bajocian-Oxfordian (Bhalla and Abbas, 1976a). Kalia and Chowdhury (1983) described this species as *Planularia anceps* from Callovian deposits of Rajasthan. Bhalla and Abbas (1978) and Bhalla and Talib (1991) described it from Callovian-Oxfordian of Kachchh. Subbotina *et al.* (1960) reported this species from Oxfordian deposits of Kachchh. *Reophax* aff. *R. scorpiurus* ranges from Bathonian to Kimmeridgian. This species is restricted within the Kimmeridian deposit of Egypt (Said and Barakat, 1958) while Basha (1983) reported it from Bathonian of Jordan. *Epistomina parastelligera* ranges from Bajocian to Kimmeridgian. Gordon (1967) recorded this species from Callovian sediments of Barora, Scotland. Nagy, *et al.*, (2001) reported it from Callovian of Scotland. Kalantari (1969) recorded it from Callovian of Iran and Said and Barakat (1958) reported this species from Callovian and Kimmeridgian of Egypt. Basha (1983) noted this species (=*Epistomina gr. parastelligera*) in Bajocian to Callovian rocks of Jordon. This species was also recovered from the Callovian-Oxfordian sediments of Poland (Olszewska and Wieczoreka, 1988). *Ammobaculites cobbani* is recorded from the Oxfordian of North American (Loeblich and Tappan, 1950a), Callovian-Oxfordian of Canada (Wall, 1960), Bajocian of Egypt (Said and Brakat, 1958), Kimmeridgian of France (Barnard and Shipp, 1981), and Callovian of Jhurio hill, Kachchh (Bhalla and Talib 1985c, 1991). Hence, the range of this species is from Bajocian to Kimmeridgian. *Vaginulinopsis misrensis* also ranges from Bajocian to Kimmeridgian. Said and Barakat (1958) reported it from Kimmeridgian of Egypt while Kalantari (1969) recovered this species from Bajocian of Iran. *Trocholina* aff. *T. conosimilis* ranges from Bathonian to Tithonian. This species was originally described from Callovian and Oxfordian of Kachchh (Subbotina *et al.*, 1960). Bhalla and Abbas (1976b, 1978) and Bhalla and Talib (1985c, 1991) reported it from Callovian-Oxfordian of Kachchh while Pandey and Dave (1993) reported it from Bathonian to Tithonian of Kachchh. Kalia and Chowdhury (1983) reported this species from Callovian deposits of Rajasthan. However, this species is mostly reported from Callovian to Oxfordian sediments (Talib and Bhalla, 2006a).

A small percentage of species having moderately long ranges within the Jurassic are also present in the Ler hill assemblage. *Reophax metensis* was first described from the Upper Pliensbachian of France (Franke, 1936). Later Said and Barakat (1958) reported it from Callovian of Egypt, Basha (1983) from Bajocian to Bathonian of Jordon, and Nagy and Johansen (1991) from Toarcian to Bajocian of North Sea. Hence, the range of this species is considered to be Pliensbachian to Callovian. *Reophax multilocularis* ranges from Toarcian to Oxfordian (Heausler, 1890; Gordon, 1967; Kalantari, 1969; Bhalla and Talib, 1991; Nagy and Johansen, 1991). *Lenticulina protracta* (=*Planularia protarcta*) is reported from Toarcian of North Sea (Nagy and Johansen, 1991), Bajocian of Iran (Kalantari, 1969), and Callovian-Oxfordian deposits of England (Barnard *et al.*, 1981). Hence, the total range of this species is from Toarcian to Oxfordian.

Few species which have considerably long ranges within the Jurassic Period have also been recovered from the present foraminiferal assemblages. *Ammobaculites fontinensis* ranges from Hettangian to Callovian. Said and Barakat (1958) reported it to range from Bathonian to Callovian of Egypt. Kalantari (1969) considered this species a representative of Bajocian in Iran. Coleman *et al.* (1981) reported it to range from Hettangian to Bathonian and Bhalla and Talib (1985c, 1991) recorded it from Callovian sediments of Kachchh. Nagy and Johansen (1991) recorded it from Toarcian to Bajocian sediments of northern North Sea and Nagy *et al.*, (2001) recovered it from Callovian of Scotland. *Citharina clathrata* is found to be confined to the Lower and Middle Jurassic sediments in various localities of the world (Bartenstein and Brand, 1937; Cifelli, 1959; Desio *et al.*, 1965; Bhalla and Abbas, 1978; Bhalla and Talib, 1991). However, Kalantari (1969) considered it as a marker species of Bajocian in Iran. *Lenticulina qünstedti* (Gümbel) ranges from Toarcian to Tithonian and has been reported from Callovian-Kimmeridgian of

Egypt (Said and Barakat, 1958) and Callovian to Oxfordian of Kachchh (Bhalla and Abbas, 1978; Bhalla and Talib, 1991). Gradstein (1978) reported this species to range from Bajocian to Kimmeridgian and Coleman *et al.* (1981) recorded it from Toarcian to Oxfordian. Govindan *et al.*, (1988) reported it from Oxfordian to Tithonian deposits of Kachchh while Pandey and Dave (1993) recovered this species from Callovian-Oxfordian and Kimmeridgian sediments of the same region.

Few species with extremely long ranges within the Jurassic were recovered from the Ler hill assemblage. *Nodosaria simplex* ranges from Hettangian to Kimmeridgian (Bhalla and Abbas 1976a, 1978; Bhalla and Talib, 1991; Said and Barakat, 1958; Kalantari, 1969). *Pseudonodosaria vulgata* (Bornemannn) also ranges from Hettangian to Kimmeridgian (Gordon, 1967; Coleman *et al.*, 1981; Nagy and Johansen, 1991; Barnard *et al.*, 1981; Barnard and Shipp, 1981). *Spirillina polygyrata* ranges from Hettangian to Tithonian (Kalantari, 1969; Bhalla and Abbas, 1976a, 1978; Said and Barakat, 1958; Olszewska and Wieczorek, 1988).

Some species which extend from Jurassic to Creteceous are also present in the present assemblage. *Epistomina tenuicostata,* is a relatively short-ranging species but extends from Late Jurassic to Early Cretaceous and has been mostly reported from Early Cretaceous sediments. Williamson (1987) described this species from Hauterivian of East Newfoundland Basin. Grigelis and Ascoli (1995) reported it from Valanginian to Hauterivian of Canadian Atlantic shelf and East European Platform. Kalantari (1969) reported *E. tenuicostata* (= *Brotzenia tenuicostata*) from Hauterivian of Iran while Gordon (1965) described this species (=*Brotzenia tenuicostrata*) from Oxfordian of England. Thus, the total range of this species may extend from Oxfordian to Hauterivian or Early Barremian.

Few species found in the present assemblage are extremely long-ranging and extend beyond Jurassic in to Cretaceous. *Lenticulina tricarinella* ranges from

Lower Jurassic to Lower Cretaceous (Said and Barakat, 1958; Gordon, 1965, 1966; Kalantari, 1969; Bhalla and Abbas, 1976a; Gradstein, 1978; Coleman *et al.*, 1981; Kalia and Chowdhury, 1983; Medd, 1983; Govindan *et al.*, 1988; Bhalla and Talib, 1991; Pandey and Dave, 1993 Talib and Bhalla, 2006a), *Lenticulina münsteri* is recorded from Late Triassic (Rhaetian) to Early Cretaceous (Hauterivian) (Macfadyen, 1935; Said and Barakat, 1958; Kalantari, 1969; Bhalla and Abbas, 1978; Barnard and Shipp, 1981; Coleman *et al.*, 1981; Hart *et al.*, 1981; Kalia and Chowdhury, 1983), *Ammobaculites subcretaceous* extends from Lower Jurassic to Cretaceous (Kalantari, 1969; Bhalla and Abbas, 1976a; Williamson, 1987; Bhalla and Talib, 1991; Pandey and Dave, 1993; Talib and Bhalla, 2006a) and *Lenticulina subalata* ranges from Lower Jurassic to Cretaceous (Said and Barakat, 1958; Kalantari, 1969; Bhalla and Abbas, 1976a; Coleman *et al.*, 1981; Barnard *et al.*, 1981; Barnard and Shipp, 1981; Basha, 1983; Medd, 1983; Bhalla and Talib, 1991; Pandey and Dave, 1993; Talib and Bhalla, 2006a)

Two species restricted within Cretaceous were also encountered in the present assemblage. These include *Haplophragmium kutchensis* Pandey and Dave (1993) reported from Neocomian of Kachchh and *Neoflabellina ovalis* (Wedekind) recorded from Santonian of Iran (Kalantari, 1969).

From the above discussion it is apparent that most of the Jurassic foraminiferal species in the present assemblage are rather long-ranging and the present assemblage exhibits lack of truly marker species. However, there are few comparatively short-ranging foraminiferal species restricted within Callovian to Oxfordian, *viz.*, *Reophax sundancensis, Frondicularia kutchensis*, *Lenticulina ectypa*, *Hemirobulina sastryi*, and *Marginulina caelata*. The present assemblage also contains few foraminiferal species which are rather long-ranging but recorded abundantly in Callovian to Oxfordian strata in different parts of the world, *viz.*, *Ammobaculites cobbani, Laevidentalina guembeli*, and *Trocholina* cf. *T. conosimilis*. Therefore, on the basis of these species a Callovian to Oxfordian age is being assigned to the studied sequence of Ler hill, Kachchh.

5.3 CALLOVIAN-OXFORDIAN BOUNDARY

As mentioned elsewhere, majority of the species of the present foraminiferal assemblage are rather long-ranging and therefore not suitable for demarcating finer subdivision of the sequence. However, on the basis of some fairly short-ranging foraminiferal species confined to or frequently occurring within a single stage, some workers have successfully demarcated the stage boundaries in different Jurassic exposures of the Kachchh region.

Bhalla and Talib (1985c) demarcated Callovian–Oxfordian boundary in the Jurassic sequence of Jhurio hill, Kachchh. Mandwal and Singh (1994) demarcated the boundary between Bathonian/Callovian and Callovian/Oxfordian strata in the Patcham-Chari formations of Jhurio hill, Kachchh. Talib and Bhalla (2006a) demarcated the Callovian-Oxfordian boundary in Jhurio hill, Kachchh. In a subsequent paper Talib *et al.* (2007) delineated the Callovian-Oxfordian boundary in the Jurassic sequences of Jumara and Jhurio hills, Kachchh.

An attempt is made here to demarcate the boundary between Callovian and Oxfordian strata in the studied sequence on the basis of some fairly short-ranging foraminiferal species either confined to or found abundantly in the Callovian or Oxfordian strata in different parts of the world.

Various species of *Epistomina* provide well delineated evolutionary sequence that can be recognized from basin to basin and are therefore most suitable for dating and correlation purposes (Ascoli, 1984). Gordon (1965) opined that species of this genus may prove to be of greater stratigraphic value than other Jurassic foraminiferal species as they appear to have restricted occurrence in different subdivisions of the Jurassic stratigraphic column. Thus, various species of *Epistomina* may prove valuable for dating and finer subdivisions of Jurassic sequences. A total of five species of Epistomina were recovered from the Ler hill foraminiferal assemblage, *viz.*, *Epistomina minutereticulata, E. parastelligera, E. regularis, E. tenuicostata,* and *Epistomina* sp. Although these species of

Epistomina are rather long-ranging but two of these, *viz., E. regularis* and *E. tenuicostata* along with other species have been used for separating the Callovian and Oxfordian strata exposed in Ler hill, Kachchh.

On the basis of foraminiferal evidence the present Chari sequence can be divided in to two parts, *i.e.,* from litho-units I to V and from litho-units VI to VII representing the Callovian and the Oxfordian respectively.

5.3.1 Lower Portion (litho-units I to V)

The lower portion from Litho-unit I to V contains some foraminiferal species representing Callovian, *viz., Epistomina regularis, Reophax metensis, Ammobaculites fontinensis,* and *Astacolus anceps.*

Epistomina regularis, though ranges from Bajocian to Callovian, is considered as a zonal marker of Callovian in Canadian Atlantic Shelf as it shows its last appearance in Callovian (Ascoli, 1988). Various workers reported *E. regularis* from Callovian strata only (Williamson and Stam, 1988; Stam, 1986; Coleman, 1981; Ascoli, 1984). Grandstein (1978) also considered this species as a zonal marker of Callovian in Grand Bank of Newfoundland. Considering Callovian as the upper age limit of *Epistomina regularis,* Mandwal and Singh (1994) demarcated the Callovian-Oxfordian boundary in the Jhurio hill section of Kachchh. This species has not yet been reported in sediments younger than Callovian. In the present Chari sequence *E. regularis* first appears in Litho-unit I and terminates in Litho-unit III.

Reophax metensis was first described from the upper Pliensbachian of Lothringen, eastern France (Franke, 1936). Nagy and Johansen (1989, 1991) reported this species from Lower Jurassic to Early Middle Jurassic (Hettangian to Bathonian) of Western Europe (North Sea). However, *R. metensis* is commonly found in the Callovian sequence of Egypt (Said and Barakat, 1958). Till now, none of the workers have reported this species from strata younger than Callovian. *R. metensis* is recovered from litho-units II and V of the study area.

Various workers on foraminifera have reported *Ammobaculites fontinensis* from Callovian and older sediments. Said and Barakat (1958) noted this species from Bathonian and Callovian of Egypt, Bhalla and Talib (1991) reported it from Callovian of Kachchh region, Nagy and Johansen (1991) reported it from Toarcian to Bajocian. *A. fontinensis* is frequently found in Bajocian of Iran (Kalantari, 1969). Bartenstein and Brand (1937) gave the stratigraphic range of this species from Upper Pliensbachian to Callovian of Germany. Although quite long-ranging this species has not been reported in sediments younger than Callovian. In the present Chari section this species is recovered from litho-units I and V. *Astacolus anceps*, though ranges from Bajocian to Oxfordian, it has been regarded by Pandey and Dave (1993) as a zonal marker of *Proteonina difflugiformis* – *Astacolus anceps* Zone of Upper Callovian age in Kachchh. This species is restricted to Litho-unit V only.

5.3.2 Upper Portion (litho-units VI to VII)

In the upper portion of the present Chari sequence, there are three species which represent Oxfordian, *viz.*, *Marginulina oxfordiana*, *Marginulina sculptilis*, and *Epistomina tenuicostata*.

Marginulina oxfordiana was first reported from Oxfordian sediments of England (Gordon, 1965). This species has also been reported from the Oxfordian sediments of Jhurio hill, Kachchh (Bhalla and Talib, 1991). Therefore, this species could be considered as a representative of Oxfordian. In the Chari sediments of Ler hill *M. oxfordiana* is found in Litho-unit VI.

Marginulina sculptilis was originally described from Oxfordian by Schwager (1865). Later Haeusler (1890) and Gordon (1965) reported this species from the Oxfordian deposits of Switzerland and England respectively. Till now this species

Figure 7

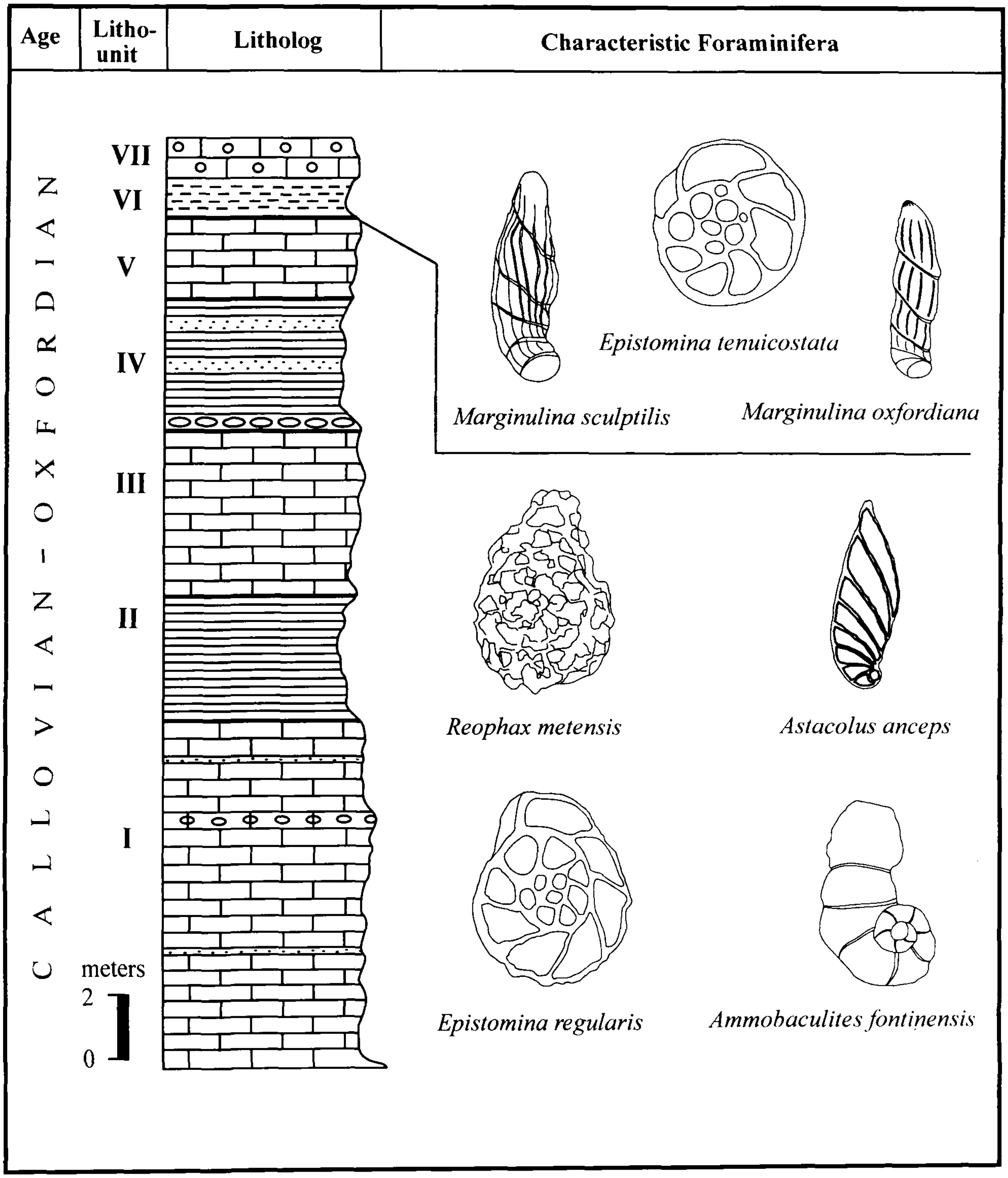


Figure 7. Callovian-Oxfordian boundary, Ler hill, Kachchh

has not been reported from rocks older than Oxfordian. In the present section, *Marginulina* aff. *M. sculptilis* is encountered in Litho-unit VI.

Epistomina tenuicostata was first reported from Valanginian of Germany (Bartenstein and Brand, 1937). Many of the subsequent workers reported this species from Early Cretaceous (Kalantari, 1969; Williamson and Stam, 1988; Grigelis and Ascoli, 1995). However, Gordon (1965) recorded this species from Oxfordian sediments of England and Coleman *et al.* (1981) reported the range of *E. tenuicostata* extending from Oxfordian to Early Cretaceous in Britain. Therefore, this species may be taken as a representative of Oxfordian in the present sequence. *E. tenuicostata* is recovered from the upper portion of Chari sequence of the study area in Litho-unit VI.

Although only a few species representative of Callovian and Oxfordian were encountered in the studied sequence which are suitable for demarcating the boundary between Callovian and Oxfordian strata but in the light of the above discussions and available evidences, it seems reasonable to conclude that in the present Chari sequence the deposition of sediments commenced during Callovian time with Litho-unit I and continued up to the Litho-unit V while the deposition of litho-units VI and VII took place during Oxfordian time. The Callovian/Oxfordian boundary in the present sequence is, therefore, marked between litho-units V and VI (figure 7).

The demarcation of Callovian-Oxfordian boundary in the present Chari sequence at Ler hill, Kachchh is, however, only tentative and needs further support from other groups of mega- and microfossils, specially, ammonites and ostracods which are abundantly found in these rocks but need detail study and revision.

CHAPTER 6

PALAEOECOLOGY

A considerable volume of literature exists on foraminiferal ecology and palaeoecology which reveals that these organisms are reliable indicators of the environment in which they live. Due to their extreme sensitiveness to the environment and abundance through major portions of the geological column, foraminifera provide valuable tool to interpret past environments at least as far back as Cretaceous (Sliter and Baker, 1972; Murray, 1991; Gebhardt, 1998) and in many cases even up to Jurassic (Barnard and Shipp, 1981; Bhalla and Abbas, 1984; Bhalla and Talib, 1991; Gebhardt, 1998; Talib and Gaur, 2005). However, when applying Cretaceous and older foraminifera to deduce the past environments, interpretations should not be based solely on comparison with modern environments and their fauna, as certain group of foraminifera have changed their environmental preferences through time. Working on ecology and paleoecology of foraminifera, several authors (Natland, 1957; Skolnick, 1958, Phleger, 1960; Burnaby, 1962; Ager, 1963) observed that with the commencement of Palaeogene Period some groups of foraminifera have changed their habitat and caution must be observed while interpreting palaeoenvironments based on pre-Palaeogene foraminifera.

Few workers (Said, 1950; Wall, 1960) consider that ecological studies should be based on individual foraminiferal species rather than genera or family as different species of a genus may thrive in a wide range of environment and, therefore, the paleoecological interpretation based on genera and family are rather unreliable. However, it is also true that palaeoecological interpretations solely based on individual species is not reliable, especially in the pre-Cretaceous sediments because certain foraminiferal species occurring in older rocks may represent entirely different environmental conditions as compared to their modern counterparts (Phelger, 1960). However, various workers (Shipp and Murray, 1981;

Bhalla and Abbas, 1984; Gebhardt, 1998; Bhalla and Talib, 1991; Nagy and Seidenkrantz, 2003; Talib and Gaur, 2005) interpreted the palaeodepositional environments of the pre-Cretaceous rocks based on foraminiferal genera and families because most of the foraminiferal species of this age do not exist in the modern time.

Jurassic foraminiferal assemblages are usually predominated by the families Vaginulinidae and Nodosariidae and both the families have unequivocally changed their habitat from shallow to deeper waters since the Mesozoic time (Barnard, 1948; Bhalla and Abbas, 1978; Coleman, 1981; Bhalla and Talib, 1991; Talib and Gaur, 2005). Furthermore, extreme variation exhibited by these families creates problems in their identification and consequently in drawing paleoecological interpretations.

Nevertheless, in spite of all these constraints several recently developed techniques are being successfully used to draw fairly accurate paleoecological interpretations based on foraminiferal assemblages. Few of the important and widely used methods are briefly discussed here.

Fisher or alpha index, $\alpha = n\,(1-x)/x$ was introduced by Fisher *et al.* (1943), where n is the number of individuals in a sample and x is a constant related to the number of species. Value of alpha (α) can be read directly from a graph (Murray 1991, p. 319). The α-index has extensively been used for characterizing modern foraminiferal environments by Murray (1973) who demonstrated that value of fisher index increases with an increase in depth. The highest α value demonstrates the lowermost slope (Murray, 1976). Apart from the bathymetry, α-diversity index also gives an idea about the salinity, temperature, and oxygen level. Different workers utilized α-diversity index to successfully interpret the palaeoecology of the Mesozoic foraminiferal assemblages (Copestake and Johanson, 1989; Morris and Coleman, 1989; Nagy *et al.*, 1990, 1995; Nagy and Seidzenkrantz, 2003). In the present study α-diversity index has been calculated to have an idea of the

Figure 8

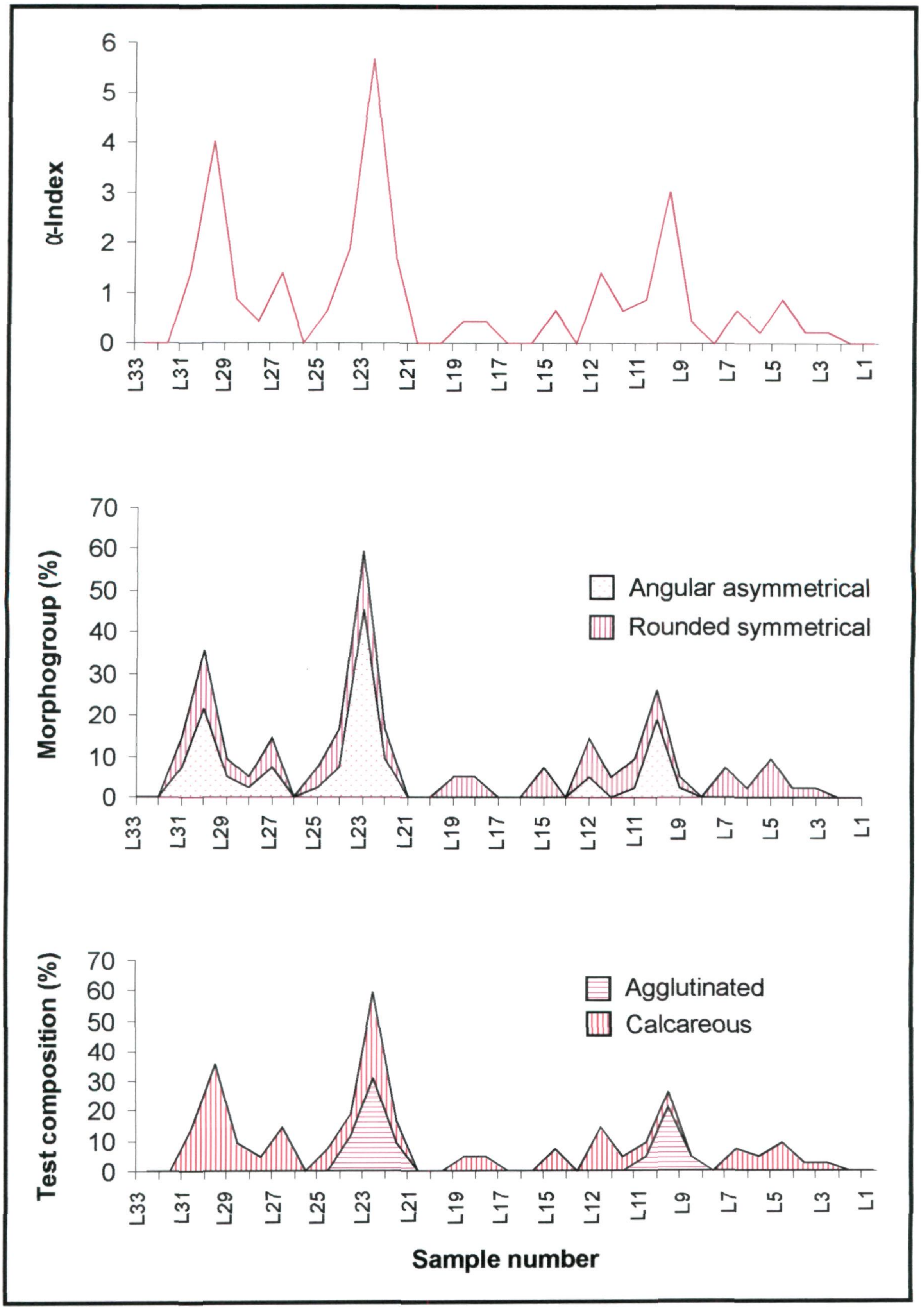


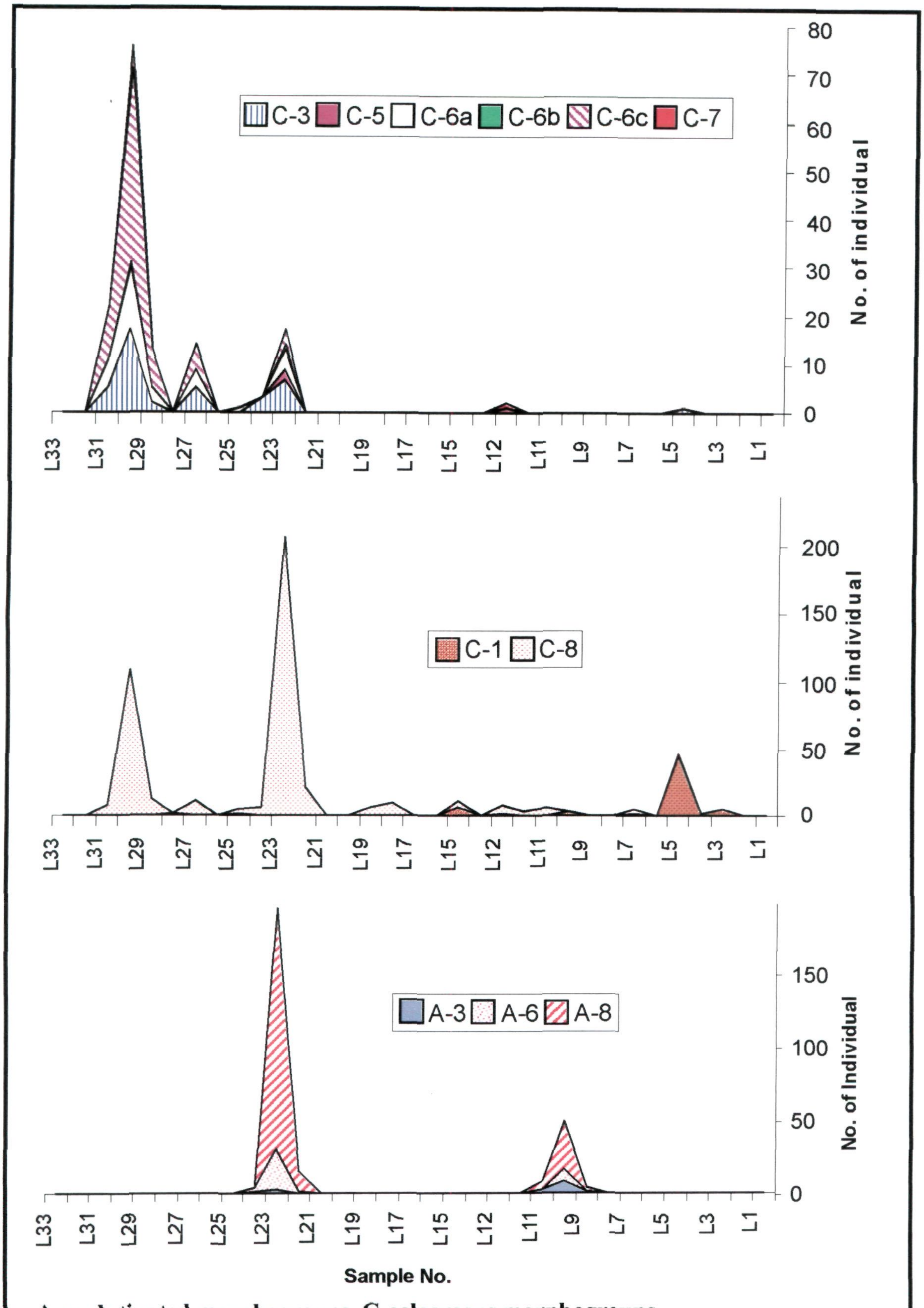
Figure 8. Distribution of foraminiferal test composition, morphogroups (after Nigam *et al.*, 1992) and α-index, Ler hill, Kachchh

relative palaeobathymetric conditions in the Jurassic sequence of Ler hill, Kachchh (figure 8).

Triangular plots, based on three types of wall structures in foraminifera, *viz*., agglutinated, porcelaneous and hyaline have also been used widely for interpretation of palaeoenvironments (Valchev, 2003). The normal marine environment (35‰ salinity) is indicated by a dominancy of calcareous tests, hyposaline realm (<32‰ salinity) is marked by agglutinated test dominancy, and hypersaline environment (>40‰ salinity) is represented by abundant porcelaneous tests. However, in the present foraminiferal assemblage, only agglutinated and hyaline tests are present. Therefore, instead of triangular plots relative percentages of agglutinated and hyaline species have been plotted (figure 8).

Foraminiferal species are almost always defined by morphology and the "morphogroup concept" is presently emerging as a simple, efficient and fairly accurate method for palaeoecological interpretations. Several workers (Sevarine, 1983; Corliss, 1985; John and Charnock, 1985; Corliss and Fois, 1990; Nagy, 1992; Tyszka, 1994; Reolid *et al*., 2008) have suggested a close relationship between foraminiferal test morphology and microhabitat. This relationship is very significant as it enable us to infer vital basic information about ancient ecosystems. Several morphogroup schemes have been established with inferred microhabitat preferences and suggested mode of feeding (Sevarine, 1983; Corliss, 1985; John and Charnock, 1985; Kaminski, 1988; Corliss and Fois, 1990; Nagy, 1992; Nigam *et al*. 2000, Tyszka, 1994; Nagy *et al*., 1995; Bak, 2004; Szydlo, 2004, 2005; Lemanska, 2005, Reolid *et al*., 2008). With the help of morphogroups bathymetry, salinity and oxygenation condition could be determined. There is no general agreement on how to categorize different oxygen levels (Demaison and Moore, 1980; Bernhard, 1986; Kaiho, 1994). However, Gebhardt (1998) has suggested a relatively simple subdivision, corresponding to Bernhard (1986) - anoxic (<0.1ml/L O_2), dysoxic (0.1-0.5 ml/L O_2), and oxic (>0.5ml/L O_2) and this is being followed in the present study.

Figure 9



A-agglutinated morphogroups, C-calcareous morphogroups

Figure 9. Distribution of foraminiferal morphogroups (after Tyszka, 1994), Ler hill, Kachchh

The benthic foraminifera are initially separated into two morphogroups, namely angular-asymmetrical and rounded-symmetrical. Angular-asymmetrical morphogroup represents somewhat deeper regions while rounded-symmetrical morphogroup indicates relatively shallower regions (Nigam *et al.*, 2000). Nagy (1992) divided the Jurassic foraminifera of North Sea delta into four morphogroups and each morphogroup was further classified into two subgroups based on their morphotypes. Tyszka (1994) grouped the Agglutinated and calcareous foraminifera into eight morphogroups, *i.e.*, A-1 to A-8 for Agglutinated forms and C-1 to C-8 for calcareous forms while C-6 is further divided into three morphogroup C-6a, C-6b and C-6c. In the present study the foraminiferal species were first grouped in to angular-asymmetrical and rounded-symmetrical morphogroups after Nigam *et al.* (2000) for interpretation of relative bathymetry (figure 8) and then morphogroup scheme of Tyszka (1994) was followed for inferring palaeooxygenation level (figure 9).

Planktonic/Benthic ratio also provides some idea about bathymetry as with increase of depth the percentage of planktonic individuals in the sample increases (Valchev, 2003). Gibson (1989) observed that under normal marine, open-oceanic condition, there is a clear trend towards increase in the percentage of planktonic foraminiferal ratio with increase in water depth in modern seas. Tau-index was introduced as bathymetric indicator by Gibson (1988). This is calculated from the palnktonic/benthic ratio and with increase in depth the Tau value also increases. Due to absence of planktonic foraminifera in the Ler hill assemblage, this method could not be applied.

Of the above discussed methods, fisher index, foraminiferal morpogroups, and relative percentages of agglutinated and hyaline test have been used in the present palaeoecological analysis. In addition to these, some available ecological data on individual foraminiferal genera and families are also incorporated as supporting evidence. A synthesis of these methods and evidences facilitated in drawing a reasonably coherent and fairly accurate picture of the palaeoecology and depositional environment of the Chari sequence exposed at Ler hill, Kachchh.

As mentioned elsewhere, the Ler hill foraminiferal assemblage is overwhelmingly dominated by the families Vaginulinidae and Nodosariidae belonging to superfamily Nodosariacea. Nodosaraicea (excluding the Polymorphinidae) primarily indicates deep water but not restricted to it, occurring frequently with other groups (Shipp and Murray, 1981). However, the depth distribution of Nodosariacea remains controversial. Some authors (Norton, 1930; Natland, 1933; Glaessner, 1945) inferred a moderately deep marine environment while others (Barnard, 1948; Brouwer, 1969; Scheibnerova, 1972; Bhalla and Abbas, 1984; Bhalla and Talib, 1991; Talib and Gaur, 2005) suggested a shallow-marine environment for this group during the Mesozoic. Nevertheless, it appears that they have shifted from near shore shallow marine waters of the Mesozoic to deep waters from Tertiary onwards but they always preferred an open marine environment with normal salinity condition (Bhalla and Abbas, 1984; Bhalla and Talib 1991; Talib and Gaur, 2005). Gordon (1970) assigned Jurassic foraminiferal assemblages dominated by Nodosariacea to shelf region while Scheibnerova (1972) suggested that the Jurassic epicontinental foraminiferal assemblages dominated by Nodosariacea indicate a shallow water neritic environment. In view of the above, the present foraminiferal assemblage is being assigned to neritic environment. However, Absence of porcelaneous tests in the present assemblage excludes the possibility of deposition in the inner neritic environment as porcelaneous tests as a rule are typical of inner shelf (Valchev, 2003). Therefore, the depositional environment appears to be generally restricted to middle and outer neritic environments.

On the basis of detailed palaeoecological analysis utilizing the above mentioned techniques, the Ler hill foraminiferal assemblage is divided into five sub-assemblages representing different bathymetric and environmental conditions. This facilitated in dividing the Ler hill sequence in to five palaeoecological units

Figure 10

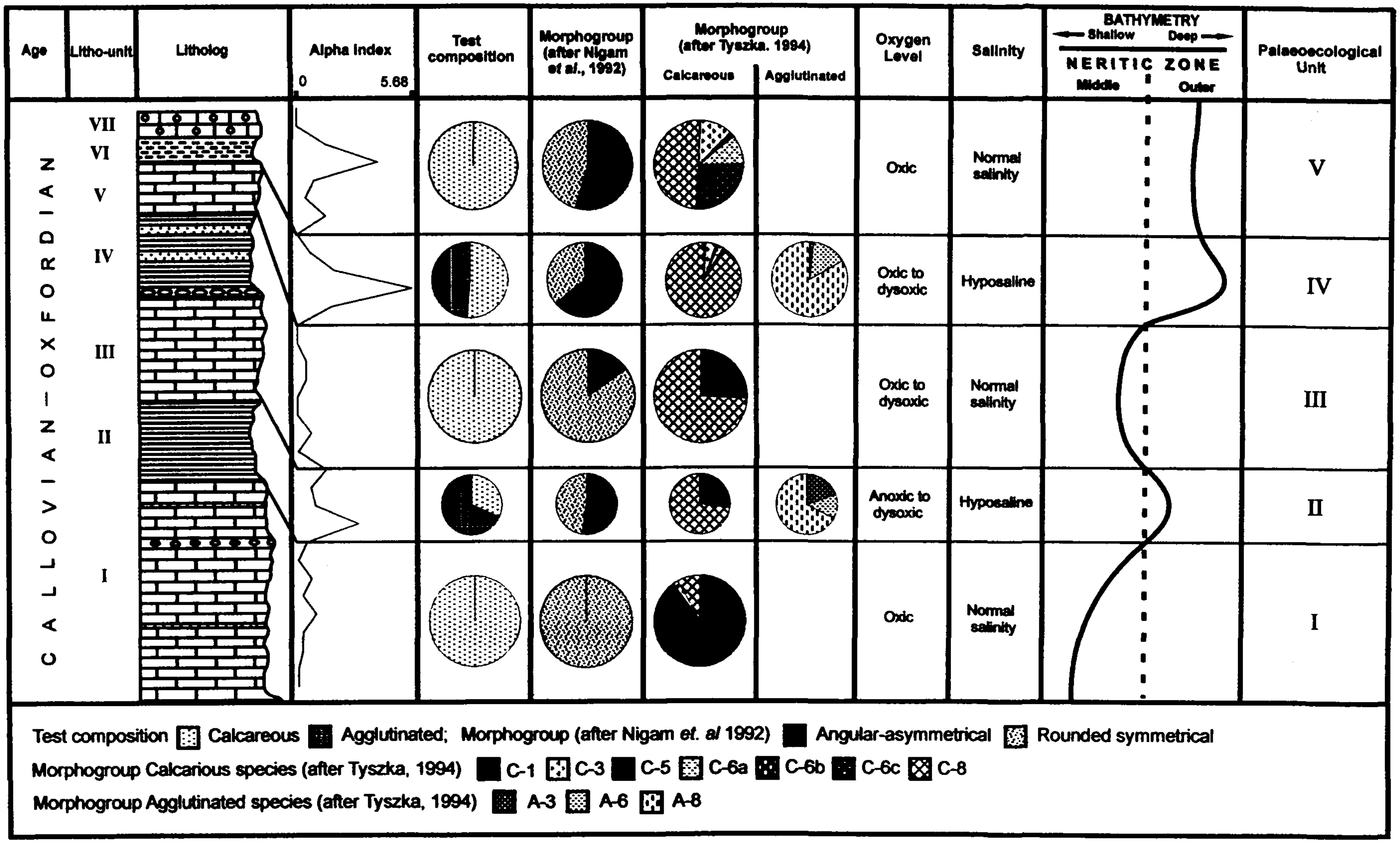


Figure 10. Main faunal parameters and inferred depositional environment of Middle-Upper Jurassic sequence, Ler, Kachchh

corresponding to these five sub-assemblages with the depositional environment fluctuating between middle to outer neritic zones (figure 10). The palaeoecology of these units is discussed below in considerable detail.

6.1 UNIT-I (SAMPLES L1 TO L8):

This is the lowermost palaeoecological unit of the Jurassic sequence at Ler hill, Kachchh. The rock types comprise predominantly limestone with few thin bands of fine to medium grained sandstone and micritic conglomerate, having bivalves. The unit is very poor in foraminiferal occurrence with a total of seven foraminiferal species belonging to three genera, represented by the families Vaginulinidae, Epistominidae, and Involutinidae.

In this unit *Trocholina* aff. *T. conosimilis*, *Lenticulina ectypa*, *L. muensteri*, and *L. subalata* are rare in occurrence. Epistominiidae is represented by *Epistomina minutereticulata* which is rare to frequent to abundant and rare to frequent specimens of *E. regularis*. A single specimen of *Epistomina* sp. was also recovered from this unit. This unit has the maximum concentration of Epistominiids.

The average α value is <1.0 which indicates fairly shallow water environment. This unit contains only rounded-symmetrical morphogroup which is considered as an indicator of relatively shallow region (Nigam, 2000). This unit is predominated by morphogroup C-1 of Tyszka (1994) having preferred infaunal habitat with better oxygen condition which is also supported by the absence of agglutinated forms in this unit (Gebhardt, 1998). Absence of agglutinated genera from this unit and the presence of exclusively hyaline tests suggest normal salinity condition.

Shipp and Murray (1981) commented that *Epistomina* appears to reflect normal marine hence possibly deeper water condition. Gordon (1970) stated that the depth significance of *Epistomina* at present day is very variable but suggested that usually shallow water condition prevail when *Epistomina* becomes conspicuous.

He (Gordon, 1970) also mentioned that the presence of this genus indicates deeper shelf condition. Barnard *et al.* (1981) and Barnard and Shipp (1981) also suggested deeper water environment for this genera with normal marine conditions.

In view of the above evidences, it is inferred that the deposition of this unit took place in relative shallow water environment within the shelf, most probably in the middle neritic region with better oxygen condition (oxic) and normal salinity.

6.2 UNIT-II (SAMPLES L9 TO L12):

Unit-II is composed exclusively of shale. The unit is represented by thirteen species belonging to nine genera and dominated by agglutinated forms with nine species. *Reophax multilocularis*, *R. sundancensis*, *Ammobaculites cobbani*, *A. fontinensis*, *A. subcretaceous*, *Haplophragmium kutchensis*, *Bigenerina* sp., *Lenticulina muensteri*, *L. subalata*, *Epistomina minuteriticulata*, and *E. regularis* are rare in occurrence while *Saccammina* cf. *S. franconica* is rare to abundance and *Reophax metensis* is rare to frequent to abundant in occurrence.

The average Fisher index value is also relatively more than the earlier unit, *i.e.*, > 1.0 indicating a deeper water environment. This unit is dominated by angular-asymmetrical morphogroup which also indicates relatively deeper water condition. This unit is represented by epifaunal to deep infaunal calcareous morphogroups C-1 and C-8 (both in low concentration) while the unit has agglutinated morphogroups A-3, A-6, and A-8. However, A-8 dominates suggesting a shallow to deep infaunal condition and anoxic to dysoxic environment. Dominance of agglutinated foraminifera indicates hyposaline condition for this unit.

In northern Germany dominant occurrence of *Ammobaculites* and *Reophax* together with other agglutinated forms are recorded from the Lower Aalenian to Lower Bajocian by Munk (1978). A Deep marine and/or restricted environment is suggested for agglutinated assemblages containing *Ammobaculites* and *Reophax* (*fide* Nagy and Johansen, 1991). However Shipp and Murray (1981) suggested that the presence of small agglutinated species probably represents shallow water condition with reduced salinity or less oxygenation condition, especially when they occur alone. Working on Kimmerdgian foraminifera from Boulonnais Barnard and Shipp (1981) opined that the fauna dominated by large agglutinating foraminiferal species is characteristic of shallow condition, while the mixed fauna represents a deeper environment. Said and Barakat (1958) described a rich foraminiferal assemblage from Jurassic sediments of Egypt dominated by Nodosariacea in which many agglutinated forms also occur. These authors (*op. cit.*) inferred moderately deep water condition for this assemblage. In recent marine sediments, the genus *Ammobaculites* occurs in shallow, brackish water but may also be found in deep, open marine environment (*i.e.*, continental shelf) in small abundance (*fide* Kottachi *et al.,* 2002). Agglutinated benthic foraminifera can survive under dysoxic to anoxic condition (Vercoutere *et al.*, 1987; Kaiho, 1994). *Reophax* is an infaunal deposit feeder in mud and sands of lagoon, shelves and bathyal region (Culver and Buzas, 1981; Murray, 1991). Schafer *et al.* (1981) observed that *Ammobaculites* and *Reophax* appear in increasing proportion with greater water depths in the North Sea.

On the basis of the above information, it may be inferred that the sedimentation in Unit-II took place in relatively deeper water condition as compared to Unit-I, most probably in outer neritic environment under anoxic to dysoxic oxygen level and hyposaline water.

6.3 UNIT-III (SAMPLES L13 TO L21):

The rock types of this Unit include limestone in upper portion while shale with conglomerate at the base. The foraminiferal species are poorly distributed through out the unit as out of nine samples, foraminifera are concentrated only in four samples, *i.e.*, sample number L13, L15, L18, and L19. Like Unit-I agglutinated forms are totally absent. A total of six species belonging to four genera are present in this unit. Nodosariacea is the dominant superfamily, represented by four species and among these, *Psuedonodosaria vulgata*, *Lenticulina muensteri*, and *Hemirobulina sastryi* are rare in occurrence while *Lenticulina subalata* is rare to frequent. Others species belong to family Epistominiidae which includes rare occurrence of *Epistomina minutereticulata* while *Epistomina regularis* is rare to frequent in occurrence. Epistominiids do not extend beyond this unit, except *Epistomina tenuicostata* which is rare in occurrence and is only confined to sample number L28.

The average Fisher index value is <1 indicating a shallower water condition. Like Unit-I, this unit is also dominated by rounded symmetrical morphogroup which indicates relatively shallow condition. The epifaunal to infaunal calcareous morphogroups C-1 and C-8 are dominating suggesting oxic to dysoxic water condition. This unit contains exclusively calcareous hyaline species suggesting a normal salinity like Unit I.

The presence of abundant brachiopods and cephalopods in this unit also suggests a shallow, calm, open-marine environment as brachiopods are known to inhabit normal marine environment with calm, clear and shallow water condition (Bhalla and Abbas, 1984).

In view of the above, Unit III appears to have deposited in a relatively shallow environment than the preceding unit. The bathymetric condition was almost equal or slightly deeper than the Unit I and in the middle neritic zone, having oxic to dysoxic waters and normal salinity.

6.4 UNIT-1V (SAMPLES L22 TO L26):

The rock type of this unit is yellowish to brownish colored limestone. The unit contains a rich foraminiferal fauna with a total of twenty-five species in which agglutinated forms are dominating, represented by thirteen species. Next to this, eleven species belong to superfamily Nodosariacea and one species to genus *Spirillina*.

Among the agglutinated forms *Reophax metensis* is frequent to abundance in occurrence; *R. multilocularis*, *Reophax* aff. *R. scorpiurus*, *R. sundancensis*, *Ammobaculites hagni*, *Kutsevella spilota*, and *Bulbobaculites vermiculus* are rare to frequent; *Bigenerina* sp. is frequent; *Saccammina* aff. *S. franconica*, *Ammobaculites cobbani*, *A. fontinensis*, *A. subcretaceous*, and *Spiroplectammina* sp. are rare in occurrence. Among the Nodosariacea *Lenticulina dilectaformis* is abundant to rare, *L. muensteri* is frequent to abundant, *L. subalata* is rare to abundant, and *L. quenstedti* is frequent in occurrence. *Laevidentalina* aff. *L. oppeli*, *Lenticulina tricarinella, Neoflabellina ovalis*, *Astacolus anceps*, *Astacolus* sp., *Vaginulinopsis misrensis*, and *Citharina clathrata* are rare while *Spirillina polygyrata* is abundant in occurrence.

This unit shows relatively deeper water condition as the average α-value is considerably high (>2) and the unit is dominated by angular asymmetrical morphogroup. Presence of shallow to deep infaunal agglutinated morphogroups A-6 and A-8, and dominated by epifaunal to deep infaunal calcareous morphogroup C-8 along with C-6c suggests that oxygenation condition of this unit varies from oxic to dysoxic. Dominancy of agglutinated species in this unit points towards hyposaline water.

Jurassic assemblages consisting predominantly of small textulariid genera are commonly attributed in literature to be restricted to marine deep water conditions as well as shallow water brackish environments (Nagy and Johansen, 1991) and in the present unit small textulariid (Textulariina) show fairly rich population.

Gordon (1970) observed that foraminiferal assemblages dominated by simple arenaceous form are indicative of cold water or low salinity condition. He (*op cit.*) further opined that if simple arenaceous forms are characteristic of cooler condition in some instances, then the abundance of arenaceous forms in Jurassic strata of northern Alaska would point towards an environment that was either on the deeper shelf or in shallower water with a cool, boreal temperature.

Among the agglutinated genera *Ammobaculites* and *Reophax* dominate this unit. As mentioned earlier, increasing proportion of these genera indicates greater water depth, both being very common on the lower slope (Schafer *et al.*, 1981).

From the above discussion it could be inferred that the sedimentation in this unit took place in deeper part of the outer neritic zone, having oxic to dysoxic environment and hyposaline waters.

6.5 UNIT-V (SAMPLES L27 TO L33):

The last paleoecological Unit-V comprises a fairly rich foraminiferal assemblage of exclusively calcareous species, represented by a total of sixteen species belonging to nine genera. This unit is dominated by the family Vaginulinidae and Nodosariidae. The main rock type is silty clay topped by oolitic limestone (Dhosa Oolite).

Among the ten genera of Vaginuliniid, *Lenticulina* dominates. Vaginuliniids include *Lenticulina muensteri*, *L. quenstedti*, *Neoflabellina ovalis*, *Margiulina oxfordiana*, and *Citharina clathrata* which are rare to abundance in occurrence while *Lenticulina subalata* is rare to frequent in this unit. *Lenticulina dilectaformis*, *L. protracta*, *Marginulina caeleta*, *Marginulina* aff. *M. scalptilis* are rare in occurrence. Nodosariids are represented by four species, *viz.*, *Laevidentalina* aff. *L. oppeli*, *L. guembeli*, *Nodosaria simplex*, and *Frondicularia kutchensis* having rare occurrence. Other species include *Sprillina polygyrata* which is rare to abundant in occurrence and *Epistomina tenuicostata* which is rare in occurrence and restricted only to sample L28.

This unit is fairly rich in foraminiferal species and all are exclusively calcareous. The bathymetric condition appears to be deeper than Unit I and III but shallower than Unit IV and about same as Unit II as indicated by relatively higher fisher index (>1) and the dominance of angular asymmetrical morphogroup. Dominance of Nodosariacea also strengthens the view of relatively deep, normal marine condition within the shelf. However, rare to abundant occurrence of *Spirillina polygyrata* which prefer shallow water condition is also found in this unit. This unit is dominated by epifaunal to deep infaunal calcareous morphogroup C-8 and shallow to deep infaunal calcareous morphogroup C-6c which indicates oxic condition. As this unit contains only calcareous foraminifera, a normal salinity condition is indicated.

In view of the above, it may be inferred that in this unit sedimentation took place in relatively deep water environment but shallower than Unit IV, most probably in the shallower part of outer neritic environment, with normal salinity and better oxygen conditions.

6.6 CONCLUSIONS

From the above discussion it may be inferred that the Chari sedimentation in all probability commenced with a near shore, shallow open marine environment in the middle neritic zone, with better oxygen condition and normal salinity (Unit-I). This was followed by deposition in deeper waters within outer neritic zone and anoxic to dysoxic condition and hyposaline environment (Unit II). Thereafter, there was a slight shallowing of the depositional site in the middle neritic region with oxic to dysoxic waters having normal salinity (Unit III). The deposition of unit IV took place in the deeper waters of outer neritic zone having oxic to dysoxic condition and hyposaline waters. This was followed by relatively shallower conditions in the shallow part of the outer neritic zone with better oxygen condition and normal salinity in which Unit V was accumulated.

On the basis of the foraminiferal evidence it is reasonable to visualize that the overall deposition of the Chari sequence exposed at Ler hill, Kachchh, took place in a near-shore, shallow marine basin and the site of deposition fluctuated between middle to outer neritic zones in a tectonically rather unstable marine shelf as indicated by frequently fluctuating shoreline. The palaeooxygen level fluctuated between oxic, dysoxic and anoxic and the salinity between normal and hyposaline waters.

Figure 11

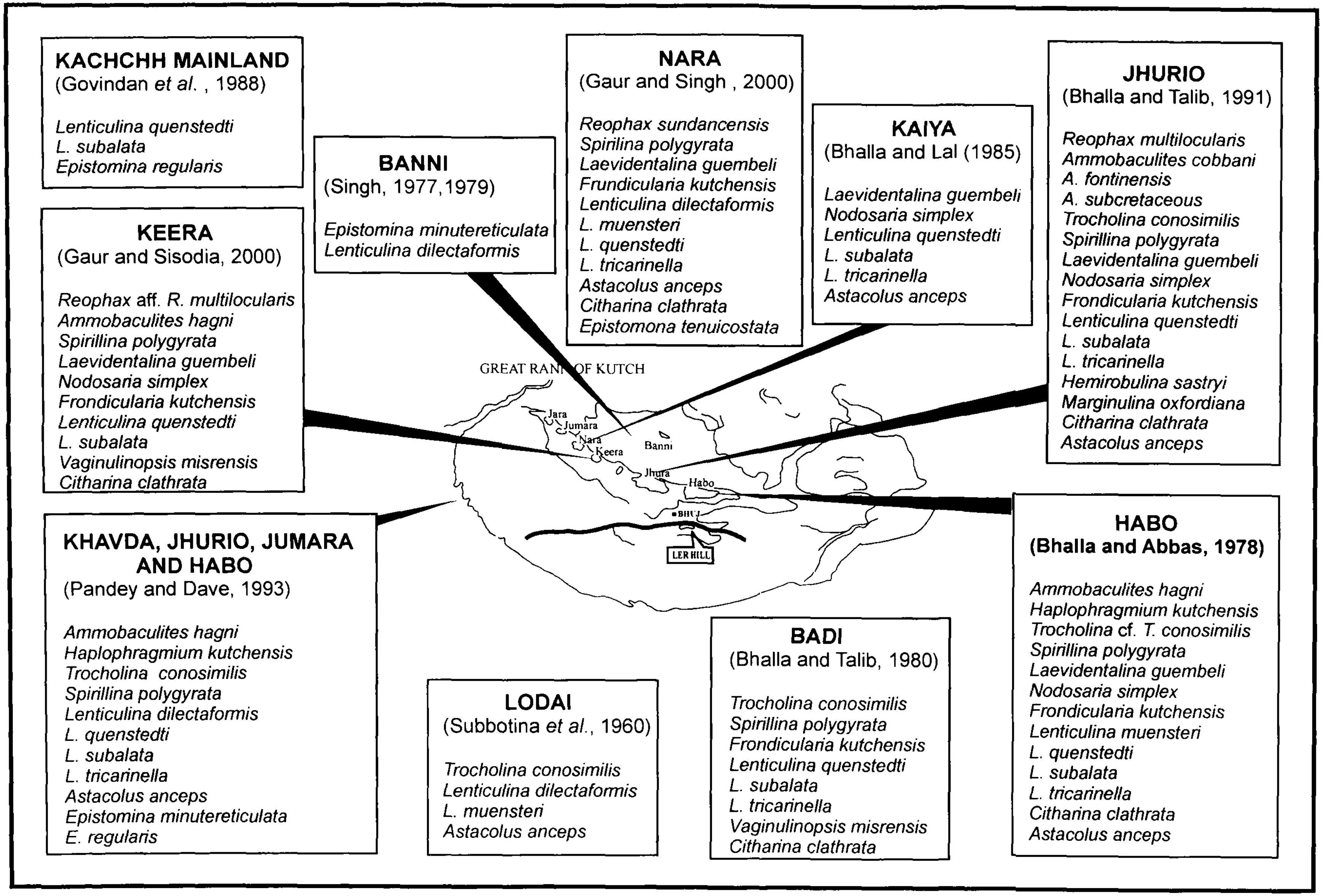


Figure 11. Affinities of foraminiferal assemblage from Ler hill with other assemblages from the Kachchh region

CHAPTER 7

AFFINITIES AND PALAEOBIOGEOGRAPHY

7.1 AFFINITIES OF FORAMINIFERAL ASSEMBLAGE

The Jurassic foraminiferal assemblage recovered from the Ler hill sequence includes a number of species widely distributed throughout the world. However, Bhalla and Abbas (1976) while discussing the affinity of Jurassic foraminiferal assemblage from Habo hills, Kachchh commented that the Jurassic foraminifera of Kachchh is endemic in nature and, as such, contribute very little in making interregional correlations. However, they also mentioned that it compares well with the assemblages described from other regions of the Tethyan Realm. An overview of literature reveals that the foraminiferal assemblage of Ler hill exhibits some affinity with the foraminiferal fauna described from other parts of Kachchh (figure 11) and other adjoining regions of the world (figure 12).

7.1.1 Indian Region

Subbotina *et al.* (1960) described a total of thirty foraminiferal species from Callovian-Oxfordian strata of Kachchh region. Among the thirty species reported four were also found in the present assemblage, *viz.*, *Trocholina* aff. *T. conosimilis*, *Lenticulina dilectaformis*, *L. muensteri*, and *Astacolus anceps*.

Singh (1977) reported five species of the genus *Epistomina* from the subsurface rocks of Banni, Kachchh. *Epistomina minutereticulata* is common to both the Banni and the present assemblage. In a subsequent paper he (Singh, 1979) described a rich assemblage of benthic foraminifera including previously reported species of *Epistomina*. *Lenticulina dilectaformis* of the Banni assemblage is also present in the Ler assemblage.

Bhalla and Abbas (1978) recovered a rich assemblage of sixty-five foraminiferal species from Jurassic sediments of Habo hills, Kachchh. Of these, twelve species are also found in the present foraminiferal assemblage. These are *Ammobaculites*

Figure 12

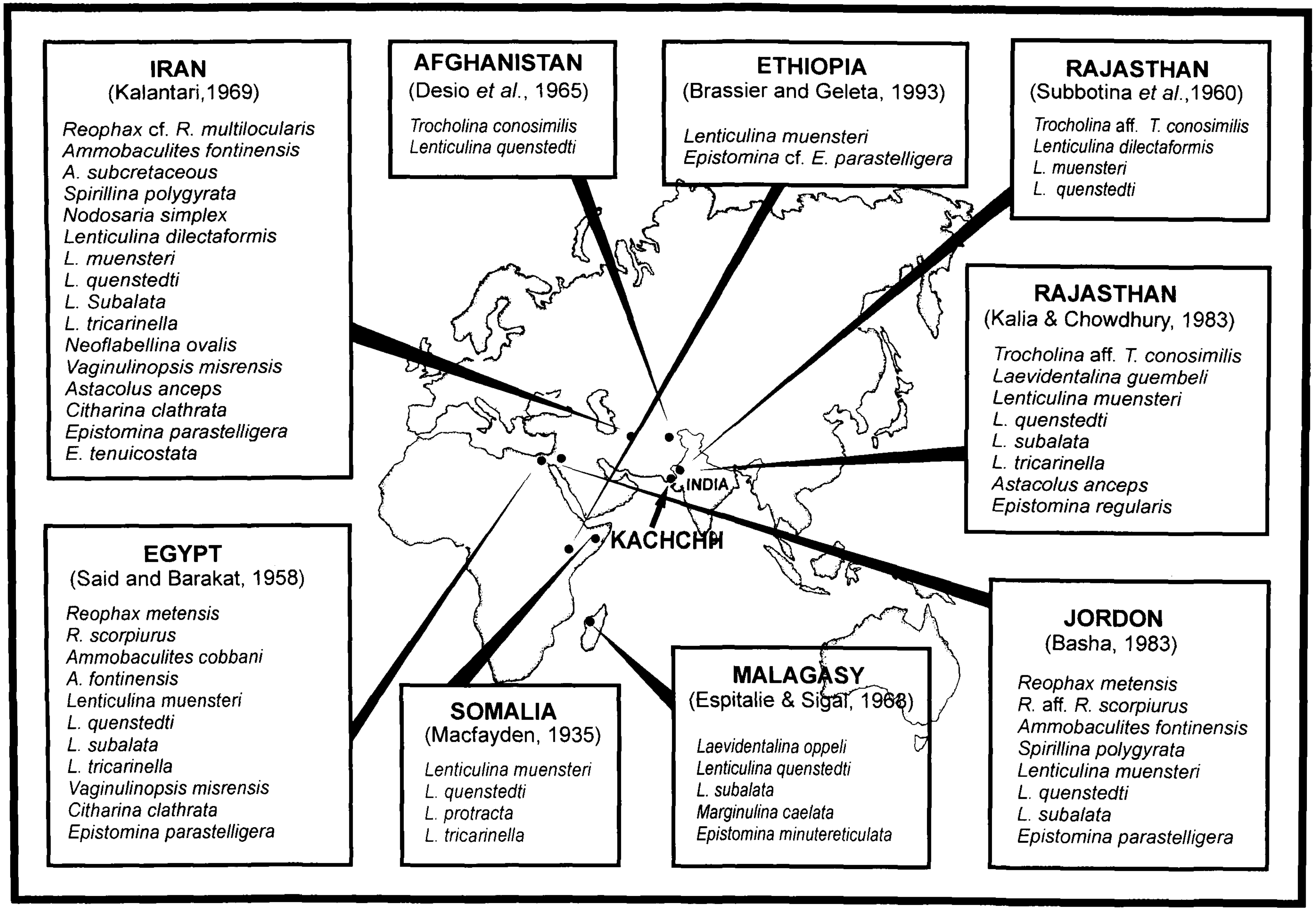


Figure 12. Affinities of foraminiferal assemblage from Ler hill with those of neighboring regions

hagni, *Haplophragmium kutchensis*, *Trocholina* aff. *T. conosimilis*, *Spirillina polygyrata*, *Laevidentalina guembeli*, *Nodosaria simplex*, *Frondicularia kutchensis*, *Lenticulina muensteri*, *L. quenstedti*, *L. subalata*, *L. tricarinella*, *Citharina clathrata*, and *Astacolus anceps*.

Bhalla and Talib (1978, 1980) described a rich population of Jurassic foraminifera from the Chari 'series' exposed near Badi village, Kachchh. *Trocholina* aff. *T. conosimilis*, *Spirillina polygyrata*, *Frondicularia kutchensis*, *Lenticulina quenstedti*, *L. subalata*, *L. tricarinella*, *Vaginulinopsis misrensis*, and *Citharina clathrata* are common to both the Badi and Ler assemblages. These authors (Bhalla and Talib, 1991) reported fifty-three foraminiferal species from Jurassic sediments of Jhurio hill, of which sixteen are also found in the present foraminiferal assemblage. These are *Reophax multilocularis*, *Ammobaculites cobbani*, *A. fontinensis*, *A. subcretaceous*, *Trocholina* aff. *T. conosimilis*. *Spirillina polygyrata*, *Laevidentalina guembeli* (= *Dentalina guembeli*), *Nodosaria simplex*, *Frondicularia kutchensis*, *Lenticulina quenstedti*, *L. subalata*, *L. tricarinella*, *Hemirobulina sastryi*, (= *Marginulina sastryi*), *Marginulina oxfordiana*, *Citharina clathrata*, and *Astacolus anceps*.

Bhalla and Lal (1985) encountered seventeen foraminiferal species from Jurassic deposits of Kaiya hill, Kachchh, out of which six are present in the Ler assemblage, *i.e.*, *Laevidentalina guembeli*, *Nodosaria simplex*, *Lenticulina quenstedti*, *L. subalata*, *L. tricarinella*, and *Astacolus anceps*.

Govindan *et al.* (1988) reported seven species of foraminifera from Jurassic strata of Kachchh, out of which *Lenticulina quenstedti*, *L. subalata*, and *Epistomina regularis* are also found to occur in the present assemblage.

Pandey and Dave (1993) described a rich assemblage of foraminiferal species from different Jurassic sections of Kachchh and eleven species described by these authors are present in the Ler assemblage. These are *Ammobaculites hagni*.

Haplophragmium kutchensis, *Trocholina* aff. *T. conosimilis*, *Spirillina polygyrata*, *Lenticulina dilectaformis*, *L. quenstedti*, *L. subalata*, *L. tricarinella*, *Astculos anceps*, *Epistomina minutereticulata*, and *E. regularis*.

Gaur and Singh (2000) described and illustrated fifty-three species of foraminifera from Jurassic sediments of Nara hill, out of which eleven species are found in the present assemblage, *viz*., *Reophax sundancensis*, *Spirillina polygyrata*, *Laevidentalina guembeli* (=*Dentalina guembeli*), *Frondicularia kutchensis*, *Lenticulina dilectaformis*, *L. muensteri*, *L. quenstedti*, *L. tricarnella*, *Astacolus anceps*, *Citharina clathrata*, and *Epistomina tenuicostata*.

Gaur and Sisodia (2000) described a prolific foraminiferal assemblage with a total of forty-one species from Chari sequence of Keera hill, Kachchh. *Reophax* aff. *R. multilocularis*, *Ammabculites hagni*, *Spirillina polygyrata*, *Laevidentalina guembeli* (=*Dentalina guembeli*), *Nodosaria simplex*, *Frondicularia kutchensis*, *Lenticulina quenstedti*, *L. subalata*, *L. tricarinella*, *Vaginulinopsis misrensis*, and *Citharina clathrata* are common to both the Keera and the Ler assemblages.

Subbotiana *et al.* (1960) encountered eleven foraminiferal species from Upper Jurassic sequence of Jaisalmer, Rajasthan. *Trocholina* aff *T. conosimilis*. *Lenticulina dilectaformis*, and *L. munsteri* are also found in the present assemblage.

Kalia and Chowdhury (1983) described a rich foraminiferal assemblage from Callovian sequence of Rajasthan. Eight species described by these authors are present in the Ler assemblage. These are *Trocholina* cf. *T. conosimilis*. *Laevidentalina guembeli* (= *Dentalina guembeli*), *Lenticulina muensteri*, *L. quenstedti*, *L. subalata*, *L. tricarinella*, *Astacolus* anceps (= *Planularia anceps*), and *Epistomina regularis*.

7.1.2 Other Adjoining Regions

Two species described by Desio *et al.* (1965) from Jurassic Karkar Formation of northeast Afghanistan are also present in the Ler hill assemblage. *Trocholina conica* recovered from Karkar Formation closely resembles *Trocholina* aff *T. conosimilis* of Kachchh while *Lenticulina quenstedti* is also present in the Ler assemblage.

A large Jurassic foraminiferal assemblage comprising 128 species has been described from the Gabel Maghara dome near Siani, Egypt by Said and Barakat (1958). A total of twelve foraminiferal species described from the Egyptian Jurassic are present in the Ler hill assemblage. These are *Reophax metensis*, *Reophax* aff. *R. scorpiurus*, *Ammobaculites cobbani*, *A. fontinensis*, *Nodosaria simplex*, *Lenticulina muensteri*, *L. quenstedti*, *L. subalata*, *L. tricarinella*, *Vaginulinopsis misrensis*, *Citharina clathrata*, and *Epistomina parastelligera*,

Kalantari (1969) described 121 foraminiferal species from Middle to Upper Jurassic (Bajocian to Kimmerdgian) sediments of northeast Iran. Sixteen species of the Iranian assemblage are also found in the Ler assemblage. These include *Reophax* cf. *R. multilocularis*, *Ammobaculites fontinensis*, *A. subcretaceous*, *Spirillina polygyrata*, *Nodosaria simplex*, *Lenticulina dilectaformis*, *L. muensteri*, *L. quenstedti*, *L. subalata*, *L. tricarnella*, *Neoflabellina ovalis*, *Vaginulinopsis misrensis*, *Citharina clathrata*, *Astculos anceps* (= *Planularia anceps*), *Epistomina parastelligera*, (= *Brotzenia parastelligera*), and *E. tenuicostata* (= *Brotzenia tenuicostata*).

Basha (1983) described seventy-seven foraminiferal species from Jurassic deposits of Jordan. *Reophax metensis*, *R.* aff. *R. scorpiurus*, *Ammobaculites fontinensis*, *Spirillina polygyrata*, *Lenticulina muensteri*, *L. quenstedti* (=*Lenticulina plexus quenstedti*), *L. subalata*, and *Epistomina parastelligera* are common to both the Jordanian and the Ler assemblage.

Brassier and Geleta (1993) reported few benthic foraminifera from the Callovian-Oxfordian strata of Ogaden Basin, Ethiopia. Two foraminiferal species, *viz.*, *Lenticulina muensteri* and *Epistomina* cf. *E. parastelligera* reported by these authors are also present in the Ler assemblage

Espitalie and Sigal (1963) encountered a rich foraminiferal assemblage from the Jurassic deposits of Malagasy. Five species, *viz.*, *Laevidentalina* aff. *L. oppeli*, *Lenticulina quenstedti*, *L. subalata*, *Marginulina caelata*, and *Epistomina minutereticulata* are common to both the regions.

Macfadyen (1935) reported twenty-four foraminiferal species from Jurassic sediments of Somalia. In the present assemblage, four species, *viz.*, *Lenticulina muensteri* (= *Cristellaria muensteri*), *L. protracta* (= *Cristellaria protracta*), *L. quenstedti* (= *Cristellaria quenstedti*), and *L. tricarinella* (= *Cristellaria tricarinella*) are found which are also present in the Somali assemblage.

7.2 PALAEOBIOGEOGRAPHY

It is well known that Jurassic was a period of worldwide marine transgression which begins from Toarcian and continued up to the Oxfordian. One of the most transgressive events in the whole Jurassic is marked by the spread of an Early Callovian sea across the Russian Platform and the west Siberian lowland of the U.S.S.R., establishing for the first time an Arctic-Tethyan link across the Eurasian landmass. (Hallam, 1978). This event is marked by widespread changes in litho- and bio-facies and appearance of new micro- and mega-fauna including foraminifera, ammonites, bivalves, gastropods, hexacoral, *etc.* Of these, ammonites are considered the most important during this period in view of their fast rate of evolution and wide as well as rapid geographical distribution.

Several workers (Neumayr, 1883; Arkel, 1956; Hallam, 1969; Gordon, 1970) believed that many Jurassic marine invertebrate faunas were not cosmopolitan in distribution but restricted to different faunal realms and they proposed different faunal realms for the Jurassic Period. Based on ammonites, Arkel (1956) identified three faunal realms, *viz.*, Boreal, Pacific and Tethyan. He (Arkel, 1956) further pointed out that during Lower and Middle Jurassic time an arm of Tethys stretched through the eastern coast of Africa which later engulfed Kachchh and western Rajasthan in India. This arm was responsible for the separation of the eastern half of the Gondwanaland from the western half and many contemporaneous fauna of the Ethiopian Province developed in this Jurassic gulf. Arkel's views have been supported by different researchers (Said and Barakat, 1958; Teichert, 1970; Bhalla and Abbas 1976b; Bhalla and Talib, 1991; Talib and Bhalla, 2006; Talib and Gaur, 2008). However, Hallam (1969) considered that only two faunal realms existed during Jurassic Period, *i.e.*, Boreal and Tethyan and merged the Pacific Realm with the Tethyan Realm as the fauna of Pacific Realm were showing mostly Tethyan characters. Gordon (1970) recognized two major foraminiferal assemblages during the Jurassic and described them as (i) shelf assemblage dominated by nodosariids, vaginulinids, and agglutinated species with simple interior and shelf calcareous species, and (ii) a Tethyan assemblage, comprising planktonic foraminifera and arenaceous foraminifera having complex internal structure in the shallow water bordering the Tethys. He defined the 'Shelf region' as an extension of Tethys in the northern and southern continental shelves while the 'Tethyan zone' was the deep geosynclinal area extending from the Mediterranean Sea to the Himalayas and further beyond to the island of Indonesia. The Tethyan assemblage of foraminifera described by Gordon is actually from shallow water areas bordering the tropical Tethys Sea. (*fide* Kalia and Chowdhury, 1983). Therefore, the definition given by Gordon for the 'Shelf' and the 'Tethys zone' on the basis of foraminifera are not explicit. Gordon (1970) further floated the idea of latitudinal bipolarity and consequently the existence of "Antiboreal" or "Austral" realm, a counterpart of the Boreal Realm in the southern hemisphere as suggested by Strakhov (1962). Scheibnerova (1972) recognized three foraminiferal biogeoprovinces during the Mesozoic including Boreal/Austral, Tethyan, and transitional biogeoprovinces. Jai Krishna (1983), based on ammonites, merged the Himalayan and the Ethipean/Indo-Malagasy provinces within the Tethyan Realm, advocated by several workers (Uhlig, 1903-10; Spath, 1933; Enay, 1973), into a single faunal province for the shallow shelf area of the Indian subcontinent. He coined the name Indo-East Africa Province which extends from East African region on the west through the above areas of the Indian subcontinent to Indonesia and New Guinea in the east and observed that this province is characterized by the presence of endemic ammonites. On the basis of abundance of epistominids and lenticulinids as well as marked scarcity of nodosariids in the foraminiferal assemblage recovered from the East European Platform, Grigelis and Ascoli (1995) opined that this kind of assemblage is neither typically Boreal nor Tethyan and could be perhaps named as "Sub-Boreal-Atlantic". These authors further suggested that both the Boreal-Atlantic and Sub-Boreal-Atlantic kind of microfauna are characterized by considerable taxonomic diversity, heterogeneity of the population, and rapid rate of evolution of lenticulinids and epistominids.

Based on the bipolar distribution of certain invertebrate groups and microorganisms, several workers have suggested the existence of an austral fauna and Austral Province or even an Austral Realm during the Jurassic period (Crame. 1983, 1986; Sha and Fursich, 1994; Kiessling and Scasso, 1996; Damborenea. 1993). Based on ammonite evidence Enay and Cariou (1997) divided the inter-tropical Tethyan fauna into Boreal and Austral Indo-Pacific. These authors (*op. cit.*) observed that from the end of the Middle Jurassic onwards the inter-tropical Tethyan fauna was split into Boreal and Austral Indo-Pacific faunas and the Austral Indo-pacific fauna extended around East and South Gondwanaland from the Himalayas to Patagonia. The Austral Indo-Pacific fauna also extended into a portion of the Tethyan region, including the eastern side of the Indo-Malagasy trough which also embraced the Kachchh region. This so-called Sub-Austral fauna, transitional to Austral Indo-Pacific fauna, flourished in the shallow water of the Indo-Malagasy seaway. These authors (Enay and Cariou, 1997) proposed the establishment of an additional ammonite Austral Realm, symmetrical to the Boreal Realm, in the southern hemisphere.

The factors controlling the distribution of Boreal and Tethyan fauna are highly debatable. Various workers on Jurassic paleozoogeography suggested different environmental factors controlling the regional distribution of Jurassic fauna. Some believed that the temperature was the main factor responsible for the distribution of fauna in different faunal realms (Neumayr, 1883; Sato, 1960; Zeilger, 1964; Jeletzky, 1965; Danovan 1967; Scheibnerova, 1972) while others considered that physical barriers were responsible for their distributions (Uhlig, 1911; Arkel, 1956; Imlay, 1965). Depth was also considered by few workers as the main controlling factor for the faunal distribution during the Jurassic (Huag, 1907; Zeilger, 1963; Ager, 1967)

Considering the similarity of ammonite fauna from Kachchh and Sub-Mediterranean regions, Krishna and Cariou (1990) suggested that the differentiation was mainly due to palaeoclimatic and palaeogeographical factors. According to them (Krishna and Cariou, 1990) the faunal exchange, which was probably controlled by eustatic sea level rise, suggests the absence of physical barrier between Europe and southeastern Gondwanaland. Instead the difference between Europe, North Africa-Arabia and Africa-Madagascar-India (differentiation of the Ethiopian Province) is supposed to have been caused by lower temperatures and gulf type shape of the south Tethys. Enay and Cariou (1997) visualized the presence of Boreal and Austral Indo-Pacific faunal provinces during Jurassic and believed that the palaeogeography of the Arctic was the prominent factor controlling the early initiation of true Boreal fauna and their differentiation from the Tethyan fauna, as the Austral Indo-Pacific and Tethyan fauna were never so clearly separated. Fürsich *et al.* (2004) suggested that the climate, synsedimentary tectonics, eustatic sea level change, and subsidence were the main controlling factors in the Jurassic marine ecosystem. Gordon (1970) suggested that the boundary between Tethyan and Boreal realms fluctuated and Boreal fauna diversified and spread strongly during Callovian, Oxfordian and Kimmeridgian times. Nagy *et al.* (1995) assumed that the Boreal fauna of Northern Hemisphere may be more cosmopolitan than known so far.

Hallam (1969) considered that the salinity to be the main factor responsible for the distribution of Boreal and Tethyan fauna. He (*op. cit.*) further considered that the Tethyan fauna exhibit arenaceous species with complex interior while Boreal Realm represents fauna with simple interior. Fürsich *et al.* (1995) suggested the salinity as one of the several environmental parameters which potentially control the distribution of benthic organism. Bhalla and Abbas (1976b) described several species belonging to Lituolacea with simple interior but which were part of an assemblage showing Tethyan affinity. These authors (*op. cit.*) discarded the salinity control hypothesis advocated by Hallam (1969) and suggested ecological conditions as the main cause of local faunal differences.

From the above discussion, it is still unclear that what was the main factor responsible for differentiation and mixing of Boreal and Tethyan faunas? However, the presence of some Boreal component in the otherwise distinctly Tethyan assemblage of Ler hill may be due to influence of global sea level rise in the Jurassic Period which could be responsible for the distribution of these faunas in the Jurassic time (Mette, 1997) .

It is a fact that the Jurassic foraminiferal assemblages from India include a number of species reported from different parts of Europe and North America (Kalia and Chowdhury, 1983). However, as suggested by Talib and Gaur (2008) this may be due to the fact that most of the early foraminifera have been reported from Europe and North America and the workers from the rest of the world have a tendency to compare their species from those of Europe and North America. Kalia and Chowdhury (1983) following the hypothesis of Gordon (1970) assigned the Rajasthan foraminiferal assemblage to "Antiboreal" with a small percentage of Tethyan elements which is characteristic of a transitional zone. They also opined that the Callovian foraminiferal assemblage of Rajasthan and the one described by Bhalla and Abbas (1978) from Callovian-Oxfordian of Kachchh have Boreal affinity as 80% of the foraminiferal species of Rajasthan and Kachchh are similar to those of Europe and North America. However, these authors did not provide concrete reasons for assigning the Jurassic foraminiferal assemblage of Rajasthan to the "Antiboreal" Realm. As suggested by Talib and Gaur (2008) citing only the number of common species is not enough to establish the biogeographic affinity of foraminiferal assemblages. In biogeographic studies, in order to firmly establish the affinities and relationships of the assemblages, a close resemblance in their morphological features and parallelism in the frequency distribution of the species must also be considered (Talib and Gaur, 2008).

Foraminiferalogists are unable to clearly establish the Jurassic foraminiferal palaeobiogeography of the western India. This is mainly because of insufficient foraminiferal data available from the Jurassic localities of the country as well as adjacent region of the world. The Jurassic foraminiferal assemblages of Kachchh exhibit affinities with the Jurassic foraminiferal assemblages described from different region of Tethyan Realm, including western Rajasthan (India). Afghanistan, Iran, Egypt, Somalia, and Malagasy (Bhalla and Abbas 1976b, 1978; Bhalla and Talib, 1991; Talib and Bhalla, 2006; Talib and Gaur, 2008) Therefore, an attempt is made here to interpret the foraminiferal palaeobiogeography of western India including the Kachchh region during the Middle to Upper Jurassic time.

The foraminiferal species of Kachchh are not only identical and or /similar in their morphological features and frequency of occurrence to those described from different parts of the Tethyan regions but there are prominent differences in morphological characters and frequency of occurrence from the foraminiferal assemblages of the Boreal Realm. Differences in morphological features and frequency of occurrence in a number of species commonly occurring in both Tethyan and Boreal realms have been discussed by Talib and Gaur (2008) in considerable detail.

Said and Barakat (1958) noticed that the Egyptian foraminiferal fauna belonging to Tethyan Realm differs from the Europian fauna having Boreal affinity in that

Figure 13

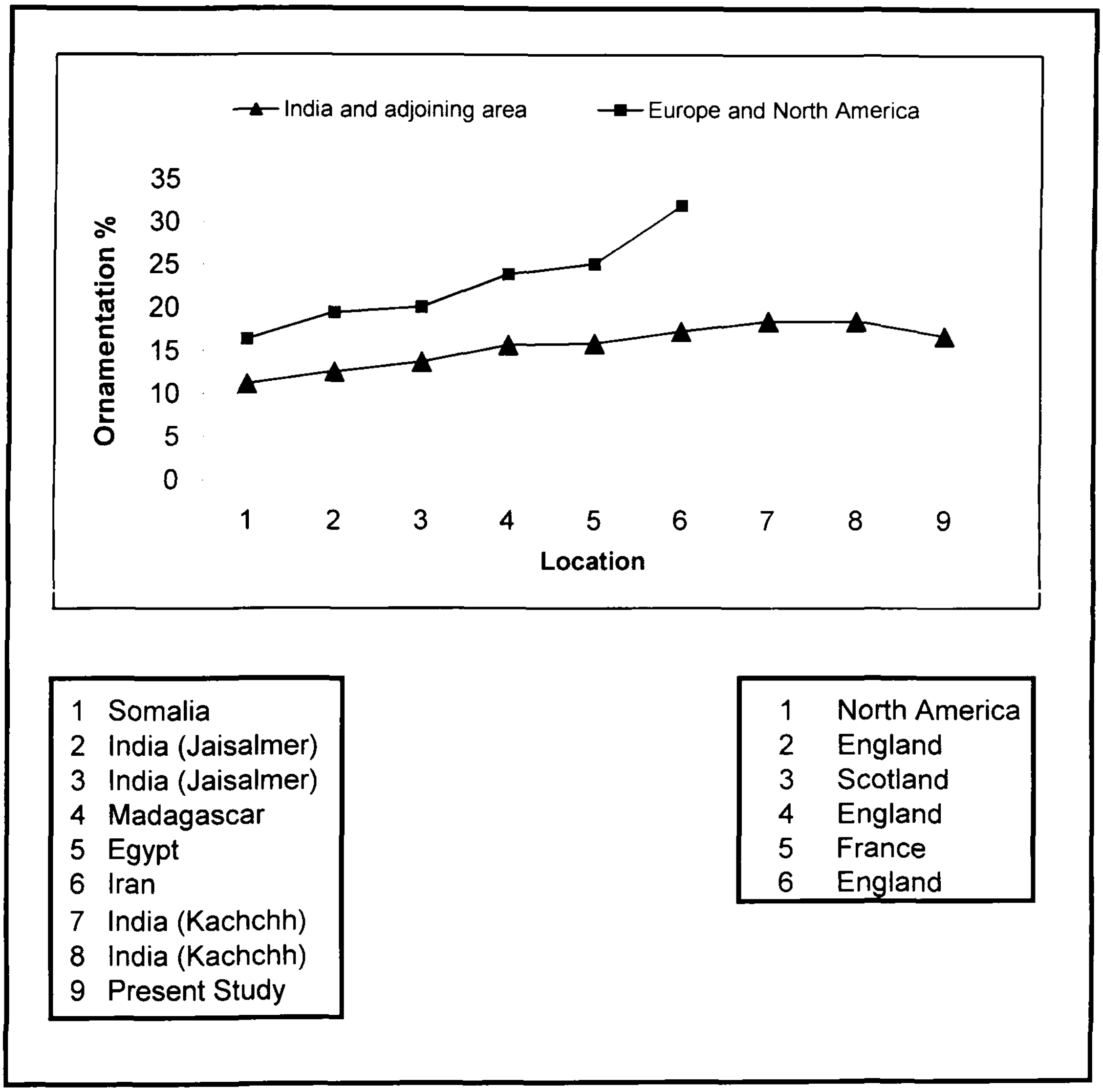


Figure 13. Comparison of ornamented species percentage in the calcareous assemblages from Tethyan and Boreal regions during Middle to Upper Jurassic

the Lageniidae are less highly ornamented in the former. In the present study an attempt is made to compare the percentages of ornamented and unornamented species among the Upper–Middle Jurassic calcareous foraminiferal assemblages from a number of Tethayn and Boreal regions of the world (figure 13). As evident from figure 13 a significant difference in the percentage of ornamented forms can be seen in Boreal and Tethyan assemblages. In the Boreal regions the percentage of ornamented test among calcareous assemblages are generally higher than those in Tethyan regions ranging from 16.32 to 31.9%. The percentage of ornamented species is 16.32 % in the foraminiferal assemblage of North America (Loeblich and Tappan, 1950a), 25% from Scotland (Gordon, 1967), 20 %, 31.9% and 19.36% from England (Gordon 1961, Gordon, 1965, and Barnard *et al.*, 1981 respectively). Barnard and Shipp (1981) reported a foraminiferal assemblage from Boulonnais (France) having 23.8% ornamented forms. In contrast Tethyan assemblages have relatively low percentages of ornamented species ranging from 11.11% to 18.36%. The ornamented forms in the Egyptian foraminiferal assemblage are 15.8% (Said and Barakat, 1958), 17.17% in the Iranian assemblage (Kalantari, 1969), and 11.11% in the Somalian assemblage (Macfadyen, 1935). Espitalie and Sigal (1963) recovered 185 foraminiferal species from Madagascar. Out of which 40 species range from Callovian to Oxfordian including 15.62 % of ornamented forms. From the Indian region 18.36 % ornamented species are found in the Kachchh region (Bhalla and Abbas, 1978; and Bhalla and Talib, 1991). Rajasthan foraminiferal assemblages described by Kalia and Chowdhury (1983) and Subbotina *et. al* (1960) contain 13.63% and 12.5% ornamented forms respectively. The Ler hill assemblage has 16.66% ornamented forms.

The above mentioned comparison suggests that the Boreal and Tethyan assemblages could be differentiated on the basis of intensity of ornamentation and clearly indicates that at least Kachchh Jurassic foraminiferal assemblages, including the present one, are not identical to the contemporary European and/or North American assemblages and exhibit a clear Tethyan affinity.

Guha (1977) suggested a close affinity of Late Jurassic ostracodes with those of Malagasy as well as East and South Africa. Same relationship was also observed by Bate (1975, 1977a) and Dingle (1988). Bate (1977b) further observed that the Jurassic ostracodes of Southern Hemisphere are quite distinct from those of Europe and North American regions. Working on ostracodes from Jurassic rocks of Kachchh, Khosla *et al.* (1997, 2004) suggested that Kachchh ostracodes have strongest affinity with those of Majunga Basin, Madagascar and to a lesser extent with Tanzania and Central Saudi Arabia. These authors (Khosla *et al.*, 1997) recovered forty-nine ostracodes from Chari Formation of Jhurio hill, Kachchh. Of these, twenty species are also recorded in the equivalent horizons of Rajasthan, Madagascar, Tanzania and Central Saudi Arabia. These authors (Khosla *et al.*, 1997) further assumed that a bay of Tethys extended southward between the east coast of the African continent and the India and Madagascar block during Middle to Late Jurassic time.

Working on mega-fossils, various authors have pointed out that the Jurassic fauna of Kachchh has a close affinity with those of Salt Range, Baluchistan, Arabia and Madagascar. (Waagan, 1873-76; Rajnath, 1942; Arkel, 1956; Pascoe, 1959; Teichert, 1970).

7.3 CONCLUSIONS

In view of the above discussions and evidences it is clear that the foraminiferal assemblage from the Ler hill as well as other Jurassic foraminiferal assemblages of Kachchh and Rajasthan exhibit a close Tethyan affinity and does not support the "Antiboreal" hypothesis or the presence of Austral Realm in this region during Middle to Upper Jurassic time. Furthermore, the presence of a subaustral fauna in this region, as opined by Enay and Cariou (1997) is also not favoured by this study. The present study supports the views of Krishna (1983) based on ammonite which favours the establishment of a separate province of the Tethyan Realm – the Indo-East African Province in the Kachchh region. Hence, the Jurassic foraminiferal assemblages of India as well as those belonging to adjoining regions

Figure 14

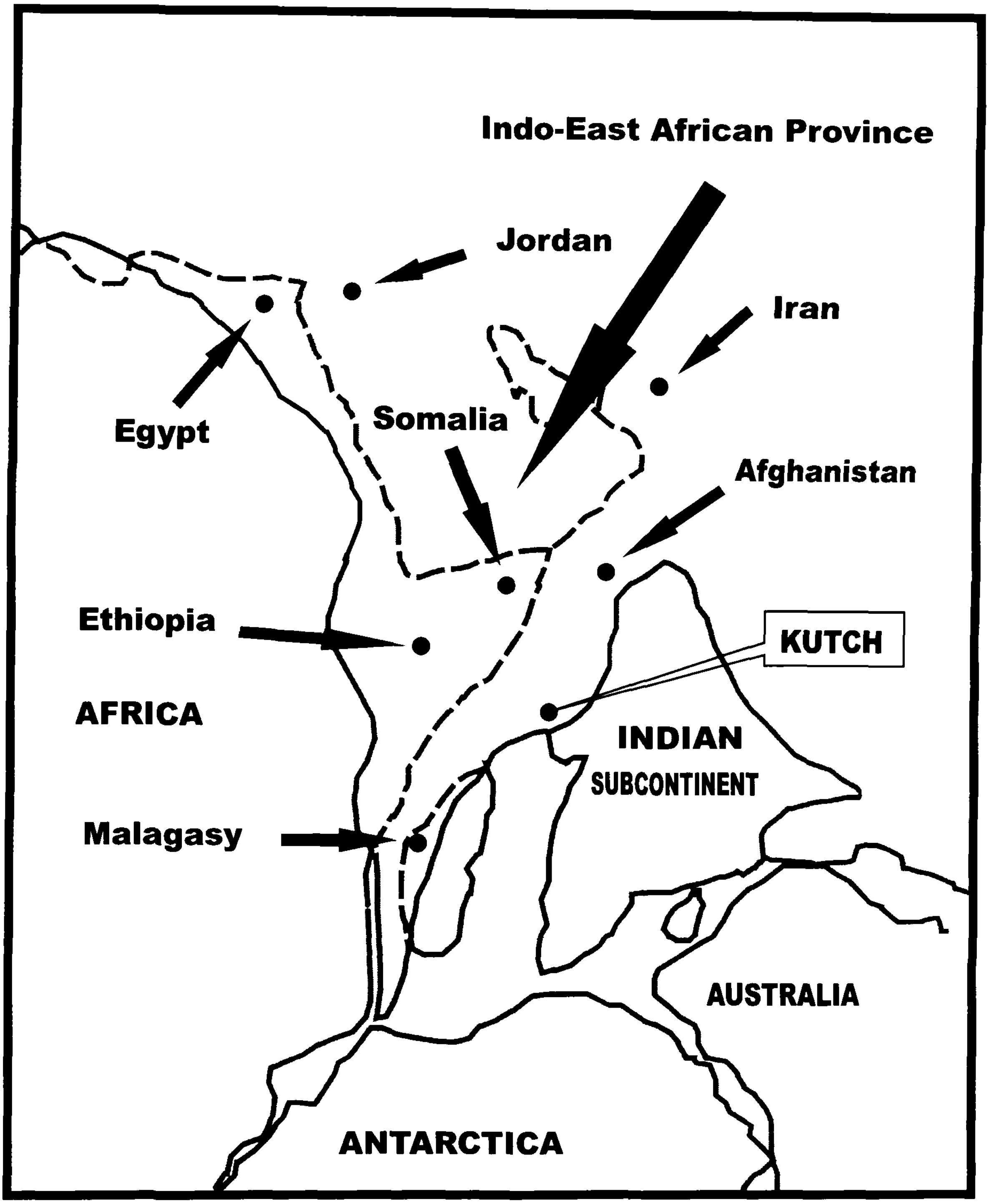


Figure 14. Palaeogeogrphy of western India including Kachchh during Middle to Upper Jurassic time showing Indo-East African Province (*modified after* Talib & Gaur, 2008; continental assembly after Enay & Cariou, 1997)

of Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia, and Malagasy belong to Indo-east African Province which was occupying the shallow water of the Indo-Malagasy or Indo-East African Gulf during Middle to Upper Jurassic times (figure 14).

It has been rather difficult to define Jurassic foraminiferal biogeography of the Kachchh region because of inadequate availability of data, as foraminifera have not been reported from many adjoining regions. However, the present study suggests that the Kachchh region was having close sea connection with Rajasthan, Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia and Malagasy during Middle to Upper Jurassic time. The foraminiferal evidence from Ler hill provides additional support to the postulations of earlier workers based on megafauna, chiefly ammonites and ostracods that during Middle and Upper Jurassic time a southwestern arm of the Tethys, the so called Indo-Malagasian or Indo-East African seaway, covered these regions in which contemporary shallow water mega- and micro-fauna, belonging to Indo-East African Province of the Tethyan Realm thrived.

SUMMARY

The foraminiferal investigations of Jurassic sequence exposed at Ler hill, Kachchh yielded a prolific assemblage from the Chari Formation while the overlying Katrol Formation is devoid of indigenous Jurassic foraminifera. A total of forty-two foraminiferal species have been identified. Of these, fifteen are being described for the first time from the Indian region. Suborder, Lagenina, having twenty-six species represents 61.90% of the total assemblage, Textulariina is represented by fourteen species (33.33%), and Involutilina and Spirillina having one species each (2.38%). The foraminiferal assemblage is dominated by the family Vaginulinidae which comprises sixteen species belonging to seven genera, covering 38.09% of the total species. Other families are Lituolidae having five species belonging to two genera (11.90%), Nodosariidae including five species belonging to four genera (11.90%), Epistominidae having five species belonging to one genus (11.90%), and Hormosinidae comprising four species of one genus (9.52%). Families Saccamminidae, Ammobaculinidae, Haplophragmiidae, Spiroplectamminidae, Textulariidae, Involutinidae, and Spirillinidae each having one species and constitute 2.38% each of the total foraminiferal species.

Although majority of the foraminiferal species are long ranging but on the basis of some short ranging species a Callovian to Oxfordian age is suggested for the entire Chari sequence exposed at Ler Hill, Kachchh. Callovian and Oxfordian boundary has been demarcated in the present area on the basis of some fairly short ranging species restricted to these stages.

Foraminiferal analysis indicates that the Chari sequence at Ler Hill was deposited in a near shore shallow, marine basin which was tectonically unstable with fluctuating shore line.

The Jurassic foraminiferal assemblage of the Ler hill compares well with those of Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia, and Madagascar and belongs

to Indo-East African Province of the Tethyan Realm. This Province occupied the shallow waters of the Indo-Malagasy or Indo-East African Gulf during Middle to Upper Jurassic times. It is further visualized that Kachchh region was having close sea connection with Rajasthan, Afghanistan, Iran, Jordan, Egypt, Somalia, Ethiopia, and Malagasy during this span of time.

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APPENDICES

APPENDIX I

α-Index VALUE OF FORAMINIFERAL ASSEMBLAGE, LER HILL, KACHCHH

Sample No.	No. of individuals	No. of species	α-index value
L33	0	0	0
L32	0	0	0
L31	29	6	1.42
L30	167	15	4.02
L29	21	4	0.88
L28	2	2	0.44
L27	24	6	1.42
L26	0	0	0
L25	5	3	0.66
L24	15	7	1.7
L23	328	25	5.68
L22	28	7	1.7
L21	0	0	0
L20	0	0	0
L19	5	2	0.44
L18	8	2	0.44
L17	0	0	0
L16	0	0	0
L15	10	3	0.66
L14	0	0	0
L13	9	6	1.42
L12	3	2	0.66
L11	11	4	0.88
L10	40	11	3.03
L9	3	2	0.44
L8	0	0	0
L7	4	3	0.66
L6	2	1	0.22
L5	32	4	0.88
L4	1	1	0.22
L3	4	1	0.22
L2	0	0	0
L1	0	0	0

APPENDIX II

TEST COMPOSITION OF FORAMINIFERAL ASSEMBLAGES, LER HILL, KACHCHH

			Total Species 42 = 100%	
Sample No.	Calcareous	Agglutinated	Calcareous (%)	Agglutinated (%)
L33	0	0	0	0
L32	0	0	0	0
L31	6	0	14.285	0
L30	15	0	35.714	0
L29	4	0	9.523	0
L28	2	0	4.76	0
L27	6	0	14.285	0
L26	0	0	0	0
L25	3	0	7.142	0
L24	3	5	7.142	11.9
L23	12	13	28.571	30.952
L22	3	4	7.142	9.532
L21	0	0	0	0
L20	0	0	0	0
L19	2	0	4.761	0
L18	2	0	4.761	0
L17	0	0	0	0
L16	0	0	0	0
L15	3	0	7.142	0
L14	0	0	0	0
L13	6	0	14.285	0
L12	2	0	4.761	0
L11	2	2	4.761	4.761
L10	2	9	4.761	21.428
L9	0	2	0	4.761
L8	0	0	0	0
L7	3	0	7.142	0
L6	2	0	4.761	0
L5	4	0	9.523	0
L4	1	0	2.38	0
L3	1	0	2.38	0
L2	0	0	0	0
L1	0	0	0	0

APPENDIX III

MORPHOGROUPS (AFTER NIGAM, *et. al.* 1992) FROM LER, KACHCHH

Angular-asymmetrical morphogroup

This group incorporates elongated flattened forms which are oval to compressed in apertural view and have either parallel or subparallel sides, straight cylindrical forms which are rounded in apertural view and have generally parallel sides in side view, and tapered form which are either rounded or angular in apertural view, and are tapered throughout their length in side view.

Reophax metensis, *R. multilocularis*, *Reophax* aff. *R. scorpiurus*, *R. sundancensis*, *Ammobaculites cobbani*, *A. fontinensis*, *A. hagni*, *A. subcretaceous*, *Kutsevella spilota*, *Bulbobaculites vermiculus*, *Spiroplectammina* sp, *Haplophragmium kutchensis*, *Bigenerina* sp., *Laevidenatlina guembeli*, *Laevidentalina* aff. *L. oppeli*, *Nodosaria simplex*, *Pseudonodosaria vulgata*, *Frondicularia kutchensis*, *Lenticulina tricarinella*, *Neoflabellina ovalis*, *Astacolus anceps*, *Astacolus* sp., *Hemirobulina sastyri*, *Marginulina caelata*, *M. oxfordiana*, *Marginulina* aff. *M. sculptilis*, *Vaginulinopsis misrensis*, *Citharina clathrata*,

Rounded-symmetrical morphogroup

This group includes trochospiral forms which have both a flattened and a more rounded side when viewed in profile (the flat side may be convex to some degree) and also those trochospiral and planispiral forms which do not have readily distinguished spiral and umbilical sides in apertural view.

Saccammina cf. *S. franconica*, *Trocholina* aff. *T. conosimilis*, *Spirillina polygyrata*, *Lenticulina dilectaformis*, *L. ectypa*, *L. muensteri*, *L. protracta*, *L. quenstedti*, *L. subalata*, *Epistomina minutereticulata*, *E. parastelligera*, *E. regularis*, *E. tenuicostata*, *Epistomina* sp.,

APPENDIX IV A

CALCAREOUS (C) MORPHOGROUPS (AFTER TYSZKA, 1994)

Sample No.	C-1	C-2	C-3	C-4	C-5	C-6a	C-6b	C-6c	C-7	C-8
L33	0	0	0	0	0	0	0	0	0	0
L32	0	0	0	0	0	0	0	0	0	0
L31	0	0	5	0	0	6	0	11	0	7
L30	0	0	17	0	5	13	1	40	0	91
L29	0	0	2	0	0	3	0	8	0	11
L28	1	0	0	0	0	0	0	0	0	1
L27	0	0	5	0	0	4	0	5	0	10
L26	0	0	0	0	0	0	0	0	0	0
L25	2	0	0	0	0	1	0	0	0	2
L24	0	0	3	0	0	0	0	0	0	5
L23	0	0	7	0	2	4	1	3	0	174
L22	0	0	0	0	0	0	0	0	0	17
L21	0	0	0	0	0	0	0	0	0	0
L20	0	0	0	0	0	0	0	0	0	0
L19	0	0	0	0	0	0	0	0	0	5
L18	0	0	0	0	0	0	0	0	0	8
L17	0	0	0	0	0	0	0	0	0	0
L16	0	0	0	0	0	0	0	0	0	0
L15	5	0	0	0	0	0	0	0	0	5
L14	0	0	0	0	0	0	0	0	0	0
L13	2	0	0	0	1	0	0	0	0	5
L12	0	0	0	0	0	0	0	0	0	3
L11	0	0	0	0	0	0	0	0	0	5
L10	3	0	0	0	0	0	0	0	0	0
L9	0	0	0	0	0	0	0	0	0	0
L8	0	0	0	0	0	0	0	0	0	0
L7	1	0	0	0	0	0	0	0	0	3
L6	0	0	0	0	0	0	0	0	0	0
L5	38	0	1	0	0	0	0	0	0	1
L4	2	0	0	0	0	0	0	0	0	0
L3	4	0	0	0	0	0	0	0	0	0
L2	0	0	0	0	0	0	0	0	0	0
L1	0	0	0	0	0	0	0	0	0	0

APPENDIX IV B

CALCAREOUS (C) MORPHOGROUPS (AFTER TYSZKA, 1994) FROM LER, KACHCHH

MORPHO -GROUP	TEST FORM	SUTURES	SPECIES FROM LER
C-1	Bi/Plano-convex Trochospiral	Raised on Spiral side	*Epistomina minutereticulata, E. parastelligera, E. regularis, E. tenuicostata, Epistomina* sp
C-2	Irregular Meandering	Depressed	
C-3	Discoidal Flattened (Planispiral) or Plano-convex (Trochospiral)	Flush to Slightly Depressed	*Trocholina* aff. *T. conosimilis, Spirillina polygyrata*
C-4	Discoidal-Flattened (Planispiral)	Slightly Depressed	
C-5	Elongated Inflated	Distinctly Depressed if Multilocular	*Laevidenatlina guembeli, Laevidentalina* aff. *L. oppeli, Nodosaria simplex, Neoflabellina ovalis, Hemirobulina sastyri*
C-6a	Elongated Flattened	Flush or Slightly Depressed	*Frondicularia kutchensis, Vaginulinopsis misrensis*
C-6b	Elongated Flattened	Flush or Slightly Depressed	*Frondicularia kutchensis, Vaginulinopsis misrensis*
C-6c	Elongated Flattened with longitudinal elongated ribs	Flush	*Marginulina caelata, M. oxfordiana, Marginulina* aff. *M. sculptilis, Lenticulina tricarinella* (uncoiled *Lenticulina*), *Citharina clathrata*
C-7	Elongated Straight Periphery	Flush or Slightly Depressed	*Pseudonodosaria vulgata*
C-8	Biconvex Lenticular	Flush or Slightly Depressed	*Lenticulina dilectaformis, L. ectypa, L. muensteri, L. protracta, L. quenstedti, L. subalata,*

APPENDIX V A

AGGLUTINATED (A) MORPHOGROUPS (AFTER TYSZKA, 1994)

Sample No.	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
L33	0	0	0	0	0	0	0	0
L32	0	0	0	0	0	0	0	0
L31	0	0	0	0	0	0	0	0
L30	0	0	0	0	0	0	0	0
L29	0	0	0	0	0	0	0	0
L28	0	0	0	0	0	0	0	0
L27	0	0	0	0	0	0	0	0
L26	0	0	0	0	0	0	0	0
L25	0	0	0	0	0	0	0	0
L24	0	0	1	0	0	2	0	0
L23	0	0	2	0	0	21	0	125
L22	0	0	0	0	0	1	0	10
L21	0	0	0	0	0	0	0	0
L20	0	0	0	0	0	0	0	0
L19	0	0	0	0	0	0	0	0
L18	0	0	0	0	0	0	0	0
L17	0	0	0	0	0	0	0	0
L16	0	0	0	0	0	0	0	0
L15	0	0	0	0	0	0	0	0
L14	0	0	0	0	0	0	0	0
L13	0	0	0	0	0	0	0	0
L12	0	0	0	0	0	0	0	0
L11	0	0	2	0	0	0	0	4
L10	0	0	6	0	0	6	0	25
L9	0	0	1	0	0	0	0	2
L8	0	0	0	0	0	0	0	0
L7	0	0	0	0	0	0	0	0
L6	0	0	0	0	0	0	0	0
L5	0	0	0	0	0	0	0	0
L4	0	0	0	0	0	0	0	0
L3	0	0	0	0	0	0	0	0
L2	0	0	0	0	0	0	0	0
L1	0	0	0	0	0	0	0	0

APPENDIX V B

AGGLUTINATED (A) MORPHOGROUPS (AFTER TYSZKA, 1994) FROM LER, KACHCHH

MORPHO -GROUP	TEST FORM	SHAPE	SPECIES FROM LER
A-1	UNILOCULAR	Tubular or Branch	*Saccammina* cf. *S. franconica*
A-2	UNILOCULAR	Plano-convex Meandering	
A-3	UNILOCULAR	Discoidal (flattened) Coiled	
A-4	MULTILOCULAR	Low Trochospiral Plano-convex or Cancavo-convex	
A-5	MULTILOCULAR	High Trochospiral (conical)	
A-6	MULTILOCULAR	Planispiral Streptospiral	*Ammobaculites cobbani*, *A. fontinensis*, *A. hagni*, *A. subcretaceous*, *Kutsevella spilota*, *Bulbobaculites vermiculus*
A-7	MULTILOCULAR	Elongated high Trochospiral	
A-8	MULTILOCULAR	Elongated uniserial/biserial	*Reophax metensis*, *R. multilocularis*, *Reophax* aff. *R. scorpiurus*, *R. sundancensis*, *Spiroplectammina* sp. *Haplophragmium kutchensis*, *Bigenerina* sp.,

APPENDIX VI A

ORNAMENTED FORMS IN THE CALCAREOUS ASSEMBLAGE OF MIDDLE-UPPER JURASSIC OF EUROPE AND NORTH AMERICA

Authors	Locations	No. of Species	No. of Agglutinated Form	Calcareous		Ornamented test among the Calcareous Assemblage (%)
				No. of Ornamented Form	No. of Smooth Form	
Loeblich and Tappan (1950a)	North America	56	7	8	41	16.32
Barnard *et al.* (1981)	England	74	12	12	50	19.36
Gordon (1961)	England	17	7	2	8	20
Barnard and Shipp (1981)	France	27	6	5	16	23.8
Gordon (1967)	Scotland	50	15	7	28	25
Gordon (1965)	England	59	12	15	32	31.9

APPENDIX VI B

ORNAMENTED FORMS IN THE CALCAREOUS ASSEMBLAGE OF MIDDLE-UPPER JURASSIC OF INDIA AND ADJOINING REGIONS

Authors	**Locations**	**No. of Species**	**No. of Agglutinated Form**	**Calcareous**		**Ornamented test among the Calcareous Assemblage (%)**
				No. of Ornamented Form	**No. of Smooth Form**	
Macfadyen (1935)	Somalia	24	4	2	18	11.11
Subbotina *et al.* (1960)	India (Jaisalmer)	8	0	1	7	12.5
Kalia and Chowdhury (1983)	India (Jaisalmer)	47	3	6	38	13.63
Epistellie and Sigal (1963)	Madagascar	185/40	3	5	32	15.62
Said and Barakat (1958)	Egypt	128	37	4	77	15.8
Kalantari (1969)	Iran	121	22	17	82	17.17
Bhalla and Abbas (1978)	India (Kachchh)	65	16	9	40	18.36
Bhalla and Talib (1991)	India (Kachchh)	53	11	13	29	18.36
Present Study	India (Kachchh)	42	14	4	24	16.66

PLATE I

Figure 1. A General View of the Ler Hill, Kachchh (view looking north).

Figure 2. A view of fossiliferous limestone (Litho-unit III) at Ler Hill, Kachchh.

Figure 1

Figure 2

PLATE II

Figure 1. Exposure of variegated shale (Litho-unit II) of Chari Formation, Ler hill, Kachchh.

Figure 2. Exposure of Conglomarate at Ler hill, Kachchh.

Figure 1

Figure 2

PLATE III

Figure 1. A view of Limestone (Litho-unit V), Ler, Kachchh.

Figure 2. Showing exposure of Bhuj Sandstone.

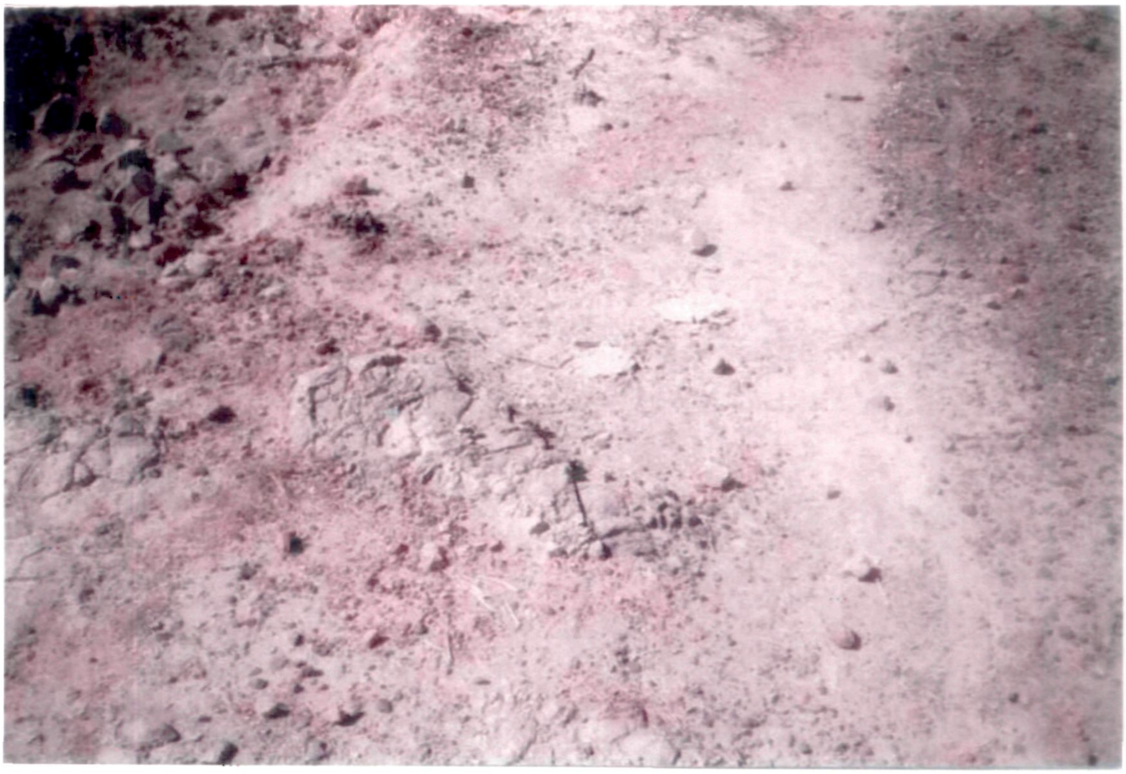

Figure 1

Figure 2

PLATE IV

(Scale Bar equals 0.1 mm in all figures)

Figures:

1	*Saccammina* cf. *S. franconica* Zielger
2	*Reophax metensis* Franke
3	*Reophax multilocularis* Haeusler
4	*Reophax* aff. *R. scorpiurus* Montfort
5	*Reophax sundancensis* Loeblich and Tappan
6	*Ammobaculites cobbani* Loeblich and Tappan
7	*Ammobaculites fontinensis* (Terquem)
8	*Ammobaculites hagni* Bhalla and Abbas
9	*Ammobaculites subcretaceous* Cushman and Alexander
10	*Kutsevella spilota* Nagy and Seidenkrantz
11	*Bulbobaculites vermiculus* Nagy and Seidenkrantz
12	*Haplophragmium kutchensis* Pandey and Dave
13	*Spiroplectammina* sp. indet.
14	*Bigenerina* sp. Indet.
15	*Trocholina* aff. *T. conosimilis* Subbotina and Srivastava
16	*Spirillina polygyrata* Guembel

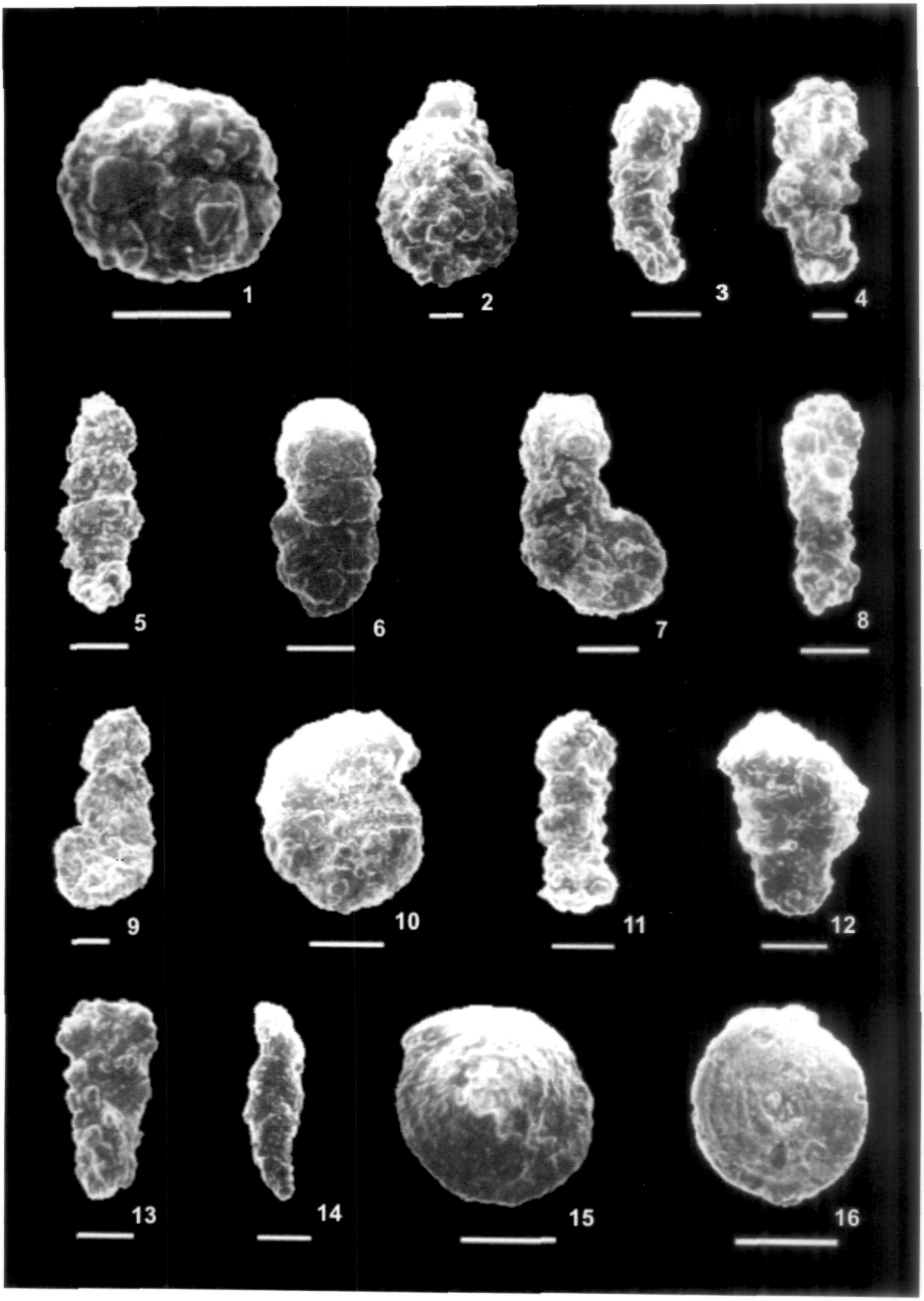
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PLATE V

(Scale Bar equals 0.1 mm in all figures)

Figures:

1. *Laevidentalina guembeli* (Schwager)
2. *Laevidentalina* aff. *D. oppeli* (Schawager)
3. *Nodosaria simplex* (Terquem)
4. *Pseudonodosaria vulgata* (Bornemann)
5. *Frondicularia kutchensis* Bhalla and Abbas
6. *Lenticulina dilectaformis* Subbotina and Srivastava
7. *Lenticulina ectypa* (Loeblich and Tappan)
8. *Lenticulina muensteri* (Roemer)
9. *Lenticulina protracta* (Bornemann)
10. *Lenticulina quenstedti* Guembel
11. *Lenticulina subalata* (Reuss)
12. *Lenticulina tricarinella* (Reuss)
13. *Neoflabellina ovalis* (Wedekind)
14. *Astacolus anceps* (Terquem)
15. *Astacolus* sp. indet.
16. *Hemirobulina sastryi* (Bhalla and Talib)

Plate V

PLATE VI

(Scale Bar equals 0.1 mm in all figures)

Figures:

1. *Marginulina caelata* Loeblich and Tappan

2. *Marginulina oxfordiana* (Gordon)

3. *Marginulina* aff. *M. sculptilis* (Schwager)

4. *Vaginulinopsis misrensis* Said and Barakat

5. *Citharina clathrata* (Terquem)

6-7 *Epistomina minutereticulata* Epistalie and Sigal

6, dorsal view; 7, ventral view

8-9 *Epistomina parastelligera* (Hofker)

8, dorsal view; 9, ventral view

10-11 *Epistomina regularis* Terquem

10, dorsal view; 11, ventral view

12-13 *Epistomina tenuicostata* Bartensten and Barnard

12, dorsal view; 13, ventral view

14-15 *Epistomina* sp. indet.

14, dorsal view; 15, ventral view

Plate VI